ILLINOIS NATURAL HISTORY SURVEY

Growth and Survival of Nearshore Fishes in Lake Michigan

F-138-R

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Center for Aquatic Ecology, Illinois Natural History Survey

Annual Report
to
Division of Fisheries
Illinois Department of Natural Resources

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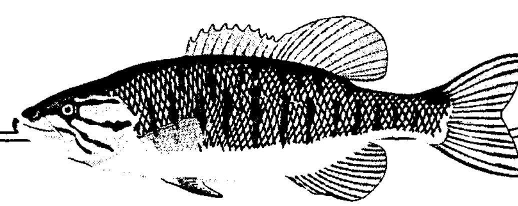
October 2003



Aquatic Ecology Technical Report 2003/14

Growth and Survival of Nearshore Fishes in Lake Michigan

August 1, 2002 – July 31, 2003

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submitted to
Division of Fisheries, Illinois Department of Natural Resources
in fulfillment of the reporting requirements of
Federal Aid Project F-138-R

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October 2003

This study is conducted under a memorandum of understanding between the Illinois Department of Natural Resources and the Board of Trustees of the University of Illinois. The actual research is performed by the Illinois Natural History Survey, a division of the Illinois Department of Natural Resources. The project is supported through Federal Aid in Sport Fish Restoration by the U.S. Fish and Wildlife Service, the Illinois Department of Natural Resources, and the Illinois Natural History Survey. The form, content, and data interpretation are the responsibility of the University of Illinois and the Illinois Natural History Survey, and not the Illinois Department of Natural Resources.

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EXECUTIVE SUMMARY

This report includes results from the past two years of a project that began in August 1998. The purpose of this project is to identify factors that contribute to and determine year-class strength of fishes in the nearshore waters of Lake Michigan. This research focuses on the Illinois waters of Lake Michigan and is needed because limited data exists on year-class strength and recruitment of nearshore fishes. The focus of this research is to describe patterns of year-class strength and try to relate these patterns to a set of factors that allow managers to better predict interannual fluctuations in fish populations.

After this project was funded, we learned that an artificial reef would be built at one of our nearshore sites. Little quantitative information exists on the role such artificial reefs play in the attraction and recruitment success of fishes in freshwater. Consequently, we added the artificial reef site (plus a nearby reference site) to our sampling protocol to identify how the addition of an artificial reef might attract sport fishes, affect recruitment success, and assess other possible effects on the nearshore fish community.

Data from sampling in 2003 are currently being processed; the results and discussion of this report are preliminary and should be interpreted as such. A complete reporting of data collected during the 2002 sampling season is presented, as well as partial information (generally through late July) from the 2003 sampling season. Further, some objectives are based on long term data collection and insights will become clearer as results accrue through future sampling; therefore, results for each objective may not be specifically discussed in this report. We present the study objectives and several research highlights below.

<u>Study 101:</u> Quantify abundance, taxonomic composition, and growth of larval fish.

1. Larval fish densities were lower than previous years at both clusters in 2002 and 2003. Mean densities at the north cluster in 2002 and 2003 were below 11 ind/100m^3. Mean larval fish densities at the south cluster were even lower, with one exception; the south cluster had a significantly higher mean density during early July 2002, with a peak of 31 ind/100m^3.
2. Larval fish species composition at the north cluster was very similar in 2002 and 2003. Yellow perch were most common in early summer, and alewife abundance increased in July. Cyprinids were more abundant in 2002 than in 2003. At the south cluster yellow perch appeared and disappeared in samples earlier than in the north cluster, and cyprinids were not as common. The south cluster also had higher densities of alewives compared to the north cluster.

<u>Study 102:</u> Quantify abundance, composition, and growth of YOY fishes > 25 mm total length.

1. Trawling was an effective sampling method only for the northern cluster. Catch per effort in 2001 was below 12 fish/100m^2 until September and then increased in October. Catch per effort peaked at 157 fish/100m^2. Catch rates were below 10 fish/100m^2 throughout the 2002 sampling season.
2. Alewife dominated trawl catches throughout 2001; spottail shiners comprised 40% of the catches in August and September. Spottail shiner and yellow perch catches

peaked earlier in 2002 than in 2001; alewife was the most common species in September and October 2002 trawls.

Study 103: Quantify nearshore zooplankton abundance and taxonomic composition.

1. Zooplankton density at the northern cluster rose above 30 ind/L during July and August in 2002, while densities at the southern cluster steadily increased throughout the sampling season up to 20 ind/L. During early 2003, the northern cluster did not approach density levels seen in 2002; densities at the south cluster reached 30 ind/L in July.
2. Zooplankton composition differed between clusters and among years. During both 2002 and 2003, nauplii comprised a larger portion of the zooplankton assemblage at the northern cluster, than at the south cluster . Both clusters exhibited peaks in rotifers during early summer 2002. but rotifers still comprised less than 5 % in late July 2003. Copepods, particularly calanoid copepods, made up a larger portion of the zooplankton community at both locations during 2003 than in 2002.
3. Zebra mussel veliger densities at the north cluster were similar in all years of study. Veliger densities at the south cluster during mid-summer 2002 and 2003 were much higher than those seen at the north cluster.

Study 104: Estimate relative abundance and taxonomic composition of benthic invertebrates.

1. Benthic invertebrate densities in 2000-2003 were higher in the northern cluster than in the southern cluster. Mean density was highest at both sites during 2002, but did not vary widely at the south sites through the years of this study.
2. Taxonomic richness of benthic invertebrates was greater in the north cluster (12 taxa) than the south cluster (4 taxa) during 2001 and 2002. Zebra mussels were the most abundant taxa at the north cluster. Chironomids and oligochaetes were common at both clusters.

Study 105: Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan.

1. Water temperatures at the southern sampling sites warmed faster and fluctuated less on a weekly basis compared to water temperatures at the north sampling sites. North water temperatures were generally cooler with a thermocline often occurring during late June through August. Peak water temperature we observed during summer 2002 occurred at both locations on August 5.

Study 106: Effects of an artificial reef on smallmouth bass abundance.

1. SCUBA divers observed round goby, rock bass, alewife, yellow perch, and juvenile and adult smallmouth bass while conducting transect swims at the artificial reef in 2000 through 2003. Smallmouth bass adults first appeared at the artificial reef when temperatures rose above 22°C during 2000 – 2002, and apparently leave the reef in mid-October. Round gobies predominated at the reference site, along with several smallmouth bass in 2000 and alewife in 2001.
2. Mean number of fish caught per net-night in gillnets did not significantly differ

between the artificial reef and reference sites. A total of 14 taxa have been collected in gillnets since 1999, most of which have been found at both locations at least once. During 2002 and 2003 smallmouth bass were collected at the artificial reef on every sampling date following late July.

INTRODUCTION

Research began in August 1998 to identify factors that contribute to and determine year-class strength of fishes in the nearshore waters of Lake Michigan. The primary goal of this research is to explore mechanisms regulating year-class strength of nearshore fishes such that managers may better predict interannual fluctuations in fish populations. This report summarizes data collected and analyzed to date from the two most recent sampling seasons. Because of the report deadline timing, sampling for 2003 is still in progress and all of the collected samples have not been processed in their entirety; complete Segment 5 results will be included in future reports of this project. F-138-R.

A "year-class" or cohort of fish is a group of individuals that is spawned in a given year (i.e.. 1998 year-class), and the number of individuals in that group that survive or "recruit" to the adult population defines the "strength" of that year-class. Frequently, year-class strength is set long before fish recruit to the adult stock or the fishable population. As a result, growth and survival of larval and juvenile fish are the primary early indicators of year-class strength. Year-class strength and recruitment of the early life-stages of fishes can be influenced by many density-independent and density-dependent factors. Fluctuations in water temperature or food availability (Houde 1994), storm or wind events (Mion et al. 1998), competition (Crowder 1980), and predation (Letcher et al. 1996) can affect growth and survival of fishes. For instance, growth is closely related to water temperatures (Letcher et al. 1997) and minor changes in daily growth can cause major changes in recruitment (Houde 1987). An overlap in the distribution of species (e.g., alewife, *Alosa pseudoharengus*; rainbow smelt, *Osmerus mordax*) may reduce the fitness of one or both species if they compete for a limited resource like zooplankton (Stewart et al. 1981). Favorable abiotic and biotic conditions have been linked to year-class strength and successful recruitment to the adult population (Lasker 1975). Therefore, understanding the factors that determine success at early life stages should help to predict fluctuations in abundance of the adult fish population.

Managing fish populations in a system as large and dynamic as Lake Michigan can be daunting when all possible variables (e.g. temperature, food availability, fishing, and pollution) are considered. To better manage the nearshore fish assemblage it is important to elucidate the primary factor or factors that regulate fluctuations in fish populations both within and among years. By identifying the factors that affect growth and survival of early life stages, primarily larval and juvenile fish, we can generate models to allow managers to predict interannual fluctuations in the adult population.

The nearshore waters of Lake Michigan support a complex assemblage of fishes. Yellow perch *Perca flavescens* and smallmouth bass *Micropterus dolomieui* are two important sport fishes, whereas alewife and spottail shiner *Notropis hudsonius* are two of the many prey fishes in this habitat. These nearshore species experience extensive variability in abundance and a few have experienced major decreases in abundance during the last decade. For example, the Lake Michigan yellow perch population supported a thriving commercial and recreational fishery in the late 1980s, but since 1988 the yellow perch population has suffered extremely poor recruitment (Pientka et al. 2002) and the fishery is now restricted. Over a recent 10-year period (1988-1997), yellow perch and alewife larvae comprised 90% of all larval fish collected in the nearshore waters of

Lake Michigan, however, since then both species overall abundance has declined in samples collected at the same locations and time frame.

We developed several study questions to address how quickly year-class strength of Lake Michigan nearshore fishes is established. These objectives were designed to explore some of the mechanisms that affect recruitment variability in the early life history of nearshore fish, including resource availability and abiotic factors. The data generated from this project will produce a better understanding of the patterns in growth and survival of early life stages of nearshore fish to estimate relative year-class strength and improve management of the resource.

After this project was funded, we learned that an artificial reef would be built in November 1999 at one of our southern sampling sites. Little quantitative information exists on the role such artificial reefs play in the recruitment success of fishes in freshwater. The proximity of the artificial reef location to our southern sampling sites allowed for sampling the reef site (plus a nearby reference site) as part of our usual sampling. Data were collected during 1999 (pre-reef construction) and 2000-2003 (post-reef construction) at the artificial reef and reference sites to determine how the artificial reef might alter production of food for fishes, affect recruitment success, and examine other possible ecological effects.

This evaluation is important in the context of our research project because a common justification for constructing artificial reefs is that they improve recruitment of fishes. However, it is not clear that these structures improve fish recruitment and production (Grossman et al. 1997). In fact, artificial reefs may simply increase harvest of fish by attracting both fish and anglers. As a result, artificial reefs may actually reduce the population of exploited game fish if they do not improve recruitment. By examining larval fish abundance, food availability, and fish density we hope to gain some insight into the possible benefits of an artificial reef for fish recruitment.

STUDY SITES

Site selection was based on a set of criteria that included water depth (3-10 m), substrate composition (soft to sandy sediments), distance from shore (<3.7 km), and geographical location (north or south) on the Illinois shoreline. The average depth of Lake Michigan nearshore waters along the Illinois shoreline is quite different from north to south. Bottom bathymetry is relatively steep in the north when compared to the south. As a result, waters deeper than 10 m are common within 1.8 – 2.7 km of shore in the north but typically do not occur until 3 nm offshore in the south. Depth differences are even more apparent when looking for water > 13 m deep. In the north, these waters can be found 3.7 km offshore, but in the south those depths are rare within 18 km of shore.

Four sample locations were selected in clusters of two, one cluster in the north near Waukegan Harbor and the other in the south near Jackson Harbor (Figure 1). Sampling northern and southern clusters facilitated the comparison of two distinct nearshore areas within southern Lake Michigan. In the north cluster a site was selected 3.7 km north of Waukegan Harbor at the mouth of the Dead River (site N1; Figure 1). N1 was selected because of the proximity to the mouth of the Dead River, an intermittent tributary of Lake Michigan. A second site just north of Waukegan Harbor (site N2) was chosen primarily for historical value. This site has been sampled since 1986 as part of a related project (F-123-R).

Site selection in the southern cluster was difficult because of numerous disruptions in the shoreline (i.e. breakwalls; harbors) and limited water depth, typically <8 m within 3.7 km of shore. One southern site was chosen directly offshore of Jackson Harbor (site S1) and the other approximately 2.2 km south of Jackson Harbor (site S2) just north of the 79th Street water filtration plant. These sites were suitable for sampling and had water depths ranging from 3-9 m with occasional depths of 10 m.

Artificial Reef

An artificial reef site selected by the Illinois Department of Natural Resources (IDNR) was located approximately 2.7 km offshore of the Museum of Science and Industry in 7.5 m of water, situated within the S1 sampling zone (Figure 1). A second "reference area" was selected approximately 2.7 km nm offshore at 7.5 m depth within the S2 sampling zone to permit comparisons between the artificial reef and an undisturbed site.

In November 1999 the artificial reef was constructed from pure granite rock of variable sizes at the location generally described above. A side scan sonar survey (Steve Anderson; Applied Marine Acoustics) on 1 April 2000 indicated that reef dimensions were: 256 m long along the centerline, mean height of 2.1 m (max 3.2 m), and mean width of 15.5 m (max 28.3 m). The reef stretches from 41° 47.600'N 87° 33.131'W (north end) to 41°47.473'N 87° 33.144'W (south end).

METHODS

All sites were sampled bi-weekly, weather permitting, except for N2 where data were collected weekly during June-July in conjunction with sampling conducted through F-123-R. Sampling was conducted from early May through late October, when possible, of each year. On each sampling date, ambient water temperature and secchi disk measurements were recorded at each site. Starting in 2002, we deployed continuously recording temperature probes at N2 and S1 to monitor hourly water temperatures throughout our sampling season.

<u>Study 101:</u> Quantify abundance, taxonomic composition, and growth of larval fish.

Job 101.1: Quantify abundance and taxonomic composition of larval fish.

Larval fish sampling was conducted from May through July using a 2x1-m frame neuston net with 500-μm (all years) and 1000-μm (1999 only) mesh netting. Neuston samples were taken at night on the surface to collect vertically migrating larval fish. Mesh size was increased before sampling on 17 June 1999 to adjust for possible net avoidance by larger and more motile larvae. We discontinued this procedure during 2000-2003 because of significantly lower catch rates associated with the 1000-μm mesh. All samples were collected within 3.7. km of shore with bottom depths ranging from 3-10 m. Neuston nets were towed for approximately 10 minutes at each site. A General Oceanics™ flow meter mounted in the net mouth was used to determine the volume of water sampled during each tow. Ichthyoplankton samples were preserved in 95% ethanol, sorted, identified to species when possible, and enumerated.

Job 101.2: Quantify growth of larval fishes.

Twenty larval fish from each taxon per date were measured (0.1 mm) and otoliths were removed from 10 of these fish to estimate daily growth (Mion et al. 1998). Otoliths were mounted, sanded to expose daily growth rings, and read under a compound microscope. Reading daily growth rings allows back calculation of length at age and estimation of growth trajectories for larval fish after swim-up (Ludsin and DeVries 1997).

<u>Study 102:</u> Quantify abundance, composition, and growth of YOY fishes > 25 mm total length.

Job 102.1 and Job 102.2: Quantify abundance, growth, and composition of YOY fishes and diet analysis.

Trawling was an ineffective sampling method in the southern cluster. Although sites were selected by substrate type (soft to sandy), intermittent exposure of boulders and bedrock flats covered with zebra mussels repeatedly prevented trawling in the south. Thus, sampling for young-of-year and juvenile fish was limited to the northern cluster. Trawling was conducted from July through October in each year. Tows of a bottom trawl (4.9-m headrope, 38-mm stretch mesh body, and 13-mm mesh cod end liner) were conducted at the north sites for a distance of 0.9 km (4460 m^2 of bottom swept) along the 3, 5, 7.5 and 10-m depth contours. Subsamples of fish from each trawl catch were preserved for length, weight, age, and diet data. Remaining fish were identified and enumerated in the field and returned to the lake. Diets of preserved fish were analyzed in the laboratory; prey taxa were identified to the lowest practical level.

<u>Study 103:</u> Quantify nearshore zooplankton abundance and taxonomic composition.

Job 103.1: Sample zooplankton at selected nearshore sites.

Replicate zooplankton samples were taken at each site at depths of 7.5 m in the southern cluster and 10 m in the northern cluster. Because zooplankton samples were collected in conjunction with other sampling (i.e., neuston or trawl), both day and night zooplankton samples were collected in some years. At each site a 73-µm mesh 0.5-m diameter plankton net was towed vertically from 0.5 m above the bottom to the surface. Sampling the entire water column generates a representative sample of the zooplankton community composition and abundance. Samples were stored immediately in 5% sugar formalin.

Job 103.2: Identify and enumerate zooplankton.

In the lab, samples were processed by examining up to three 5-ml subsamples, taken from adjusted volumes that provided a count of at least 20 individuals of the most dominant taxa. Zooplankton were enumerated and identified into the following categories: cyclopoid copepodites, calanoid copepodites, copepod nauplii, rotifers, cladocerans to genus (*Daphnia* to species), Macrothrididae spp., Sididae spp., and *Dreissena polymorpha* veligers. Uncommon and exotic taxa were noted.

<u>Studv 104:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates.

Job 104.1 Sample benthic invertebrates at selected nearshore locations.

SCUBA divers collected benthic invertebrates at a depth of 7.5 m at each site using a 7.5-cm diameter core sampler. Four replicate samples from the top 7.5 cm of the soft substrate were collected and preserved in 95% ethanol (Fullerton et al. 1998). When soft to sandy substrate sediments were limited, especially in the southern cluster, sample depth was reduced to 3.75 cm and/or fewer replicates were taken.

Job 104.2 Count and identify benthic invertebrates.

In the lab, samples were sieved through a 500-µm mesh net to remove sand. Organisms were sorted from the remaining sediment debris. Organisms were identified to the lowest practicable level, typically to genus; total length (mm) and head capsule width were measured for each individual. All taxa were enumerated and total density estimates were calculated.

<u>Studv 105:</u> Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan.

To develop predictive relationships with year class strength of nearshore fishes, we are collecting data for a variety of biotic and abiotic factors. Zooplankton densities provide information on prey availability for larval and YOY fish, which can also be related to fish growth. Water temperature data can be related to fish hatching dates and growth. Larval fish density data can provide some insight into the initial size of a year class, while YOY data gives an indication of the early survival of that year class. Each of the various factors examined may have the potential to explain some of the variability in year class strength of nearshore fishes in the Illinois waters of Lake Michigan.

For this report, predictive models were not developed. Instead, patterns in mean densities and taxonomic composition at the two clusters were compared. Differences between clusters and among years were determined using ANOVA and multiple comparison tests. Data within each cluster were compared for significant differences before pooling data for analysis between clusters. Variables that did not meet the assumptions of parametric statistics were log-transformed to either normalize distributions, stabilize the variance, or both. We considered $\alpha < 0.05$ to be significant for all analyses.

<u>Studv 106:</u> Effects of an artificial reef on smallmouth bass abundance.

Job 106.1: Relative abundance of smallmouth bass observed during SCUBA dives.

In 1999, sampling was conducted by two SCUBA divers swimming along 100-m transect lines at the artificial reef and reference sites to estimate relative fish composition and abundance before reef construction. In 2000 through 2003, divers swam the entire length of the reef (256 m) and swam at the reference site for a duration of 10 min (2000, 2002, 2003) or 20 min (2001).

Divers swam in tandem, identifying and counting fish within 2 m on either side of each diver. Divers moved at the same rate along transects to maintain equal encounter rate. At the surface, divers documented estimates and discussed the relative size composition of the observed species. The behavior of round goby prevented accurate enumeration of individuals, therefore divers recorded percent coverage of gobies in each area. Transect data will be used to determine how adding an artificial rock structure to nearshore waters influences abundance and relative composition of the fish assemblage. During 2002 and 2003 one diver swam the transect with an underwater video camera.

Job 106.2: Relative abundance of smallmouth bass collected by gill nets.

Monofilament gill nets 61 m x 1.52 m with one each 30.5-m panel of 10.2-cm and 11.5-cm stretch mesh were set at the artificial reef and reference sites during 1999 - 2001. During the 2002 and 2003 sampling season, one 30.5 m panel of 5.1 cm and one of 7.6 cm stretch mesh were added to the gillnets, making them 122 m long x 1.5 m high. The order of panels for each gillnet was randomly assigned. On each sampling date, paired nets were fished on the bottom from approximately one hour before sunset to one hour after sunrise. All fish were identified and measured, and stomach contents were pumped from smallmouth bass.

RESULTS

Results are reported for May 2002 through August 18, 2003 for artificial reef sampling and May 2002 through late July, 2003 for other methods. Data collection and processing continues for 2003; thus these results consist of all Segment 4 data and a portion of the 2003 data (Segment 5). Complete 2003 data will be reported in the Segment 6 report. The total number of field samples collected through August 18, 2003 have been included to demonstrate the types and quantity of samples collected during the entire study period (Tables 1 and 2). Differences in number of samples collected at sites in the northern cluster result from additional sampling at N2 by project F-123-R. There are generally fewer samples at the southern cluster due to more frequent cancellations of sample outings because of unsafe weather conditions.

<u>Study 101:</u> Quantify abundance, taxonomic composition, and growth of larval fish.

Job 101.1: Quantify abundance and taxonomic composition of larval fish.

Larval fish densities have remained low throughout the study period compared to densities in the 1980s and early 1990s. Mean annual larval fish density at the north cluster was approximately 4.5 ind/100m^3 during 2001 – 2003. There were no peak densities at the north cluster in 2002 or early 2003, all mean densities were below 10 ind/100m^3 (Figure 2). Annual mean density at the south cluster in 2002 was 7.5 ± 2.8 ind/100m^3. During May – June 2003, mean larval fish density was 2.8 ± 0.9 ind/100m^3. South cluster larval fish density peaked during early July 2002 at 30.4 ± 10.3 ind/100m^3, which was significantly higher ($F = 4.17$, $p = 0.00$) than the north cluster (Figure 2). Larval fish densities at the north and south clusters did not significantly differ during any other time period in 2002 and 2003. Densities at both clusters during 2003 were lower than densities in the same time period during 2002.

Total larval fish densities were significantly different between the north and south cluster at least once during 2001 and 2002, but not in any other year. However, when analyzing species composition, different patterns emerged among clusters and years. At the north cluster in 2002, yellow perch and cyprinid densities were highest early in the summer, whereas alewife densities peaked in late July (Figure 3). Yellow perch larvae were first collected at the south cluster in early May of 2002, and peaked in early June, which was earlier than observed at the north cluster. Alewife densities also peaked earlier and at a higher density in the south cluster than at the north cluster in 2002; alewife densities in early July were over 20 ind/100 m^3 (Figure 3). During 2003, yellow perch densities were again highest in late June at the north cluster, with densities slightly higher than in 2002. Densities of all species at the south cluster were low in 2003 compared to 2002. There was no large spike in alewife densities observed in early July 2003 similar to the peak observed in 2002 (Figure 4).

Job 101.2: Quantify growth of larval fish.

Otoliths have been removed and mounted for ten individuals of each taxa from 2002 larval fish samples. To date, these otoliths have not been aged. We are still validating our larval fish otolith aging techniques, and working out software glitches with our new digital camera that is used to take images of the otoliths for aging. Otoliths from 2003 nearshore larval fish have not yet been removed or mounted.

Study 102: Quantify abundance, composition, and growth of YOY fishes > 25 mm total length.

Job 102.1: Quantify abundance, growth, and composition of YOY fishes.

Bottom trawling was successfully conducted at the north cluster 1999-2002; data for 2003 is still being collected and has not been analyzed. During 2001, trawl catches were below 12 fish/100m^2 of bottom area swept during August and September and then steadily increased during October (Figure 5). Mean density was lowest on September 6 (0.11 fish/100m^2) and peaked at 157 fish/100m^2 of bottom area swept on October 23. Catch per unit effort in 2002 trawls was significantly lower than in 2001; mean catch per effort was below 10 fish/100 m^2 during all sampling periods, with the highest catch rates in early October (Figure 5).

During 2001, alewife dominated the trawl catches at N2 on all sampling dates. Mean densities of alewife in late October were over 125/100m^2 of bottom area swept (Figure 6). Spottail shiners were the second most abundant species in early August and late September; their density peaked in late October 2001 at 8.2 fish/100 m^2. Catch per effort of yellow perch in 2001 trawls was very low except in early October (Figure 6). During 2002, yellow perch relative abundance was higher early in the season, compared to late in the season during 2001. As in 2001, alewife relative abundance increased during October 2002, but their relative abundance was nearly an order of magnitude lower (Figure 6).

Job 102.2: Diet analysis of YOY fishes.

Young of the year diets have been analyzed for yellow perch collected in 2001 and 2002 trawls. Samples from 2003 trawls have not yet been processed. Stomach analysis for other trawl species. such as alewife and spottail shiner, is currently underway. For 2001, a total of 29 stomachs were analyzed; 5 of 7 sampling dates had fewer than 3 yellow perch available for diet analysis. Chironmids and copepod zooplankton were most prevalent early, whereas amphipods were most common in September and October (Figure 7). This shift may also be a result of the low sample sizes; amphipods were the most common item on October 3, which had 19 stomachs examined. A total of 117 YOY yellow perch stomachs were analyzed from 2002 trawls, however, the majority of these came from the first two sampling dates in August. Cladocerans and copepod zooplankton were very common in the diets through mid-September, until a shift to chironomids and amphipods occurred (Figure 7). *Bosmina* sp. was the most dominant prey item found in all stomachs, followed by calanoid copepods.

<u>Study 103:</u> Quantify nearshore zooplankton abundance and taxonomic composition.

Job 103.2: Identify and enumerate zooplankton.

Zooplankton densities fluctuated throughout this study at both clusters, but overall have remained low since 1999. Annual mean density in 2002 was 20.8 ± 0.8 ind/L in the north cluster and 8.0 ± 1.2 ind/L in the south cluster. Average density for June through early August, 2003 was 10.4 ± 1.8 ind/L in the north cluster and 15.3 ± 2.9 ind/L in the south cluster. Zooplankton densities in May and June of 2002 were similar to those in 2003 (Figure 8). Although the south cluster consistently had higher mean densities than the north cluster during 2001, the opposite trend appeared in 2002. North cluster densities were significantly higher than the south cluster during 4 sampling periods in 2002 (Figure 8). Samples from early July 2002 in the north cluster have the highest mean zooplankton density in this study since late August of 1999. During 2003, the opposite trend was observed, and density was higher at the southern cluster in July. However, no zooplankton samples were collected in early July at the north cluster due to poor weather conditions (Figure 8).

Species composition of the nearshore zooplankton assemblage also changed in both clusters during the course of this study. The southern zooplankton assemblage during May 2002 mirrored that of the north; nauplii accounted for 60 – 80% of the zooplankton. Nauplii remained a large component of the zooplankton at the north cluster throughout the sampling season, whereas percent composition of nauplii at the south cluster decreased greatly during June (Figure 9). This also appears to be the case so far in 2003. Calanoid copepod percent composition peaked in late-June during both years and at both clusters (Figures 9 & 10). During 2003, calanoid copepod presence was much higher at the north cluster (up to 70%) compared to levels seen in 2002 (Figures 9 & 10). The percentage of calanoid copepods was also higher in 2003 at the south cluster than the previous year. Generally, the south cluster zooplankton assemblage was comprised of more rotifers and *Bosmina* during early fall 2002 than seen at the north cluster (Figure 9). *Bosmina* peaked earlier in the southern cluster and reached up to 70% of the population, whereas percent composition reached a maximum of 45% at the north cluster (Figure 9). Although an early spike in percent composition of rotifers occurred during 2002 at both clusters, the importance of rotifers in the zooplankton assemblage was very low during this same time period in 2003 (Figure 10). Larger zooplankton taxa such as *Daphnia* sp.

made up a very small portion of the nearshore zooplankton assemblage during all study years.

Densities for veligers, the planktonic larval stage of zebra mussels *Dreissena polymorpha*, were calculated separately from other zooplankton taxa. Veliger densities peaked at 60 ind/L during 2000 at the north cluster, and 25 ind/L during 2001 at the south cluster. Although the north cluster densities for 2002 and 2003 were similar to these levels, densities at the south cluster during the past two sampling seasons were much higher. In 2002, densities peaked at the same time in both clusters, but mean density at the south cluster reached over 220 ind/L compared to 35 ind/L in the north (Figure 11). In 2003, there was also a very large peak in veliger density during late July at the south cluster, averaging 130 ind/L. Densities in the north cluster during early 2003 were below 20 ind/L (Figure 11).

Cercopagis pengoi, an exotic cladoceran, was first collected in 1999 zooplankton samples. In 2000 through 2003 *C. pengoi* began appearing in zooplankton samples from both clusters during late July. Maximum densities during 2002 were 0.13 ind/L at the south cluster and 0.05 ind/L at the north cluster. Another exotic cladoceran, *Bythotrephes longimanus*, was found on only one date at the north cluster during 2002 and never at the south cluster. It has not been observed at either cluster so far in 2003.

<u>Study 104:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates.

Job 104.1 and Job 104.2: Sample benthic invertebrates at selected locations and count and identify invertebrates.

Thirty-two benthic core samples were collected at each cluster during June through October, 2002; and 16 samples at each cluster have been collected to date in 2003 (Tables 1 & 2). During 1999 - 2002, annual mean benthic invertebrate density ranged from 424 to 3948 ind/m^2 at the north cluster and 176 to 459 ind/m^2 of bottom at the south cluster. Annual densities at both clusters were highest in 2002. The density of benthic invertebrates at the north cluster was significantly higher than at the south cluster during 2002 ($F = 7.67$, $p = 0.01$) and 2003 ($F = 17.35$, $p = 0.00$). South cluster densities were very similar in July and September, 2002, and also did not differ widely during June and July, 2003 (Figure 12). Mean monthly density at the north cluster in 2002 peaked during August (Figure 12), and was primarily due to abundant juvenile zebra mussels that had recently settled out of the water column (Figure 13).

The taxonomic richness of benthic invertebrates during 2002 differed between clusters, with 12 taxa present in the north, but only 3 in the south. Chironomids, oligocheates, and zebra mussels were the most common taxa in the north, whereas chironomids and oligochaetes were at the southern cluster (Figure 13). Zebra mussels contributed over 2000 ind/100 m^2 to the total mean benthic invertebrate density of the north cluster during all months in 2002 (Figure 13). Densities of amphipods in the north cluster were low compared to other taxa, but were not present in any south cluster samples during 2002. Chironomid densities were the most similar of all taxa between the two clusters (Figure 13).

<u>Study 105:</u> Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan.

Job 105.1: Develop predictive models of year class strength of nearshore fishes.

Predictive modeling incorporating the biotic and abiotic data collected will begin when all 2003 samples are processed, giving us a full five year dataset to work with. We have however, explored the effect temperature may have on several of the biotic variables we measured. Summer water temperatures at the northern and southern clusters exhibited similar trends from 1999 through 2003. Water at the southern cluster warmed faster and temperatures fluctuated less than in the north cluster during all five years of study. Water temperatures gradually rose above 10°C by mid-June at the north cluster. Water temperatures in the south however, were generally above 10°C in late-May and reached 15 -17°C by mid-June. Analysis of thermal logger data at the end of the 2002 season provided a good picture of temperature peaks and fluctuations at both sites during 2002 (Figure 14). Water temperatures at both clusters increased greatly in early July and climbed above 22°C on July 6, 2002. Peak water temperature during 2002 at both clusters occurred on August 5; 24.1°C at the northern cluster and 24.6°C at the southern cluster (Figure 14).

Profile sampling during 2003 provided only a snapshot picture and we may have missed actual peak water temperatures and fluctuations, which will be available after retrieval of thermal loggers in late October, 2003. Surface water temperatures at the north cluster warmed relatively quickly in 2003, but declined sharply during late June (Figure 15). Peak water temperature recorded during our profiles was 23.5°C on August 18. Temperature profiles at the south cluster showed a gradual increase in surface temperature throughout the summer, with a high temperature of 23.7°C on August 20, 2003 (Figure 15).

Although surface water temperatures followed very similar patterns at both clusters during 2002, bottom temperatures fluctuated more in the northern cluster. During all years of sampling, a thermocline was established in the north cluster at the 10 m sites. Bottom temperatures rose above 20°C in early July, 2002 but dipped below 15°C on five dates from early July through late August, down to 8°C on August 22. A distinct thermocline was not as prominent at the southern cluster during summer. South cluster bottom temperatures remained above 15°C from early July through mid/late September in 1999 – 2003 (Figures 14 & 15).

<u>Study 106:</u> Effects of an artificial reef on smallmouth bass abundance.

Job 106.1: Relative abundance of smallmouth bass observed during SCUBA dives.

Divers have encountered greater species diversity and fish abundance at the artificial reef site since its construction in 1999; only round gobies were observed prior to construction (Table 3). Since 2000, five to seven fish species have been observed each year during dives at the artificial reef. Divers have also observed increased species diversity at the reference site since 1999, however the number of fish species (2 - 4) each year and total number of fish has been lower than at the artificial reef (Tables 3 & 4).

A total of 15 transects were swum during 2002 (Table 1), and dive observations at both sites were similar to the previous two years. Fish abundance and diversity continued to be higher at the artificial reef site (Table 3). Round goby remained the most prevalent species observed at the reference site: it was the only species present on all but 3 sampling dates. Solitary yellow perch, rock bass, alewife, and carp also were observed on various dates at the reference site (Table 4). Fish species diversity at the artificial reef increased after May 5, when only round gobies were observed. Round goby, yellow perch, rock bass, juvenile smallmouth bass, and an alewife school were all present on the next sampling date, June 24. Rock bass were seen on every subsequent sampling date until October 1, whereas yellow perch were not observed again until August 14. June 24 was the earliest date that juvenile smallmouth bass had been observed at the artificial reef site in all years of the study. Adult smallmouth bass were first seen on July16, 2002; their numbers reached 43 and 44 during mid-August and mid-September (Table 3). Smallmouth bass adults were still present on the very last dive of the season. The first sighting of yearling largemouth bass at the artificial reef during any year of this study also occurred during 2002. They were also first observed on July 16 and were seen through August 28 (Table 3).

Job 106.2: Relative abundance of smallmouth bass collected by gill nets.

When looking at all fish species together, gillnet catches did not differ between the artificial reef and reference site in 2002 and 2003 (Figure 16). Patterns in number of fish caught throughout the sampling season were very similar at both locations and among years. Mean number of fish per net-night was generally around 10 fish, with several catches above this (Figure 16). Catch rates in 2002 and 2003 at both locations were highest during late June and early July.

The addition of medium size mesh panels (5.1 and 7.6 cm stretch) to gillnets in the 2002 and 2003 sampling seasons greatly changed the percent composition and abundance of the catches from previous years at both the reference and artificial reef sites. While the total number of fish caught at each site on each sampling date was never above 18 in previous years, mean number of fish caught per net-night at both sites often exceeded 15 in 2002 and 2003 (Figure 16). The major contribution to this increase in total catch was the large number of yellow perch caught in the medium mesh panels, especially during late June and early July. Annual mean number of yellow perch per net-night collected in medium mesh gillnet panels during 2002, was over three times that of any other species at both locations (Figure 17). Smallmouth bass and rock bass were the next most commonly caught species at the artificial reef, whereas freshwater drum and gizzard shad were more common at the reference site (Figure 17). Round gobies and rock bass were captured for the first time in gillnets at the artificial reef in 2002.

Smallmouth bass first appeared in gillnets at the artificial reef site on July 30, 2002 and July 29, 2003 (Figure 18). Rock bass also first appeared on July 30, 2002 but were not seen in reef gillnets during 2003 until August 14, when they were also caught at the reference site. During both years, these two fish species were caught on all subsequent sampling dates at the artificial reef. Number of smallmouth bass found in gillnets at the artificial reef so far during 2003 has been lower than the corresponding time period in 2002 (Figure 18). Smallmouth bass were present in reference site gillnets on only two dates, August 29 and October 1, 2002. One smallmouth bass was caught at the reference site on June 24, 2003, although no more have been caught so far at that location (Figure 18). Gizzard shad were first caught in reference site gillnets in mid-July

2002, but did not appear at the reef site until late August. Gizzard shad did not appear in 2003 gillnets until August 18, when they were caught at the reference site. On July 14. 2003 the only species caught in nets at either location was yellow perch. When these nets were retrieved they were thickly covered in green filamentous algae. which likely reduced their catch efficiency because they were more visible to fish.

DISCUSSSION

The patterns observed after five years of study demonstrate that mechanisms influencing fish assemblages and recruitment may operate at localized spatial scales (i.e.<100km). Clearly, temporal changes in the abundance of fish also occur. Qualitative differences in abiotic and biotic conditions that could influence larval fish recruitment success have been observed between our north and south sampling clusters. Water temperature and composition of larval fish, zooplankton, and benthic invertebrates all differed between clusters and years. Continued monitoring is needed to build a long term data set to help determine the impact these differences may have on fish recruitment in the nearshore waters of Lake Michigan.

One factor that stands out as a possible influence on the ecology of each cluster is water temperature. Water temperature is a very important variable for growth and production of fish because it influences rates of metabolism and foraging activity. and indirectly mediates biotic interactions (Hinz and Wiley 1997). Timing of reproduction for fish and other organisms is often closely linked to water temperatures. Fish larvae were often collected at the south cluster, where water temperatures rose faster. earlier than at the north cluster. The relatively cooler temperature regime in the northern cluster compared to the south appeared to be more suitable habitat for sticklebacks and the amphipod *Diporeia hoyi,* which both prefer cool water temperatures (Becker 1983: Pennak 1973); these species were not collected in the southern cluster. These relationships suggest that water temperature may account for some of the variation in biota observed between clusters and years.

Zooplankton abundance and composition may be another factor affecting growth and survival of nearshore larval fish and thus recruitment to the adult population. Overall zooplankton densities during 2000 – 2003 were low compared to densities present in the Illinois waters of Lake Michigan during 1988-1990 and 1996-1999 (Dettmers et al. 2003). During larval fish sampling from May through late July 2000. zooplankton densities were above 20 ind/L on only one date in both clusters. There was no peak in zooplankton abundance during 2001, and densities were consistently below 20 ind/L. The trend of very low densities at the south cluster continued during 2002. but densities were higher than the previous two years at the north cluster. Densities declined again in 2003 at the north cluster. Along with the continued decrease in zooplankton abundance in each year from 2000 - 2003, there was also a corresponding decrease in larval fish abundance. This was likely due to poor survival of larval fish at both locations because of the low zooplankton densities.

Zooplankton species composition and body size can regulate growth of age-0 yellow perch (Mills et al. 1989; Confer et al. 1990), thus eventually affecting overwinter survival and recruitment. A recent lab experiment showed that growth of newly hatched larvae was greater for perch feeding on copepod nauplii compared to rotifers (Graeb et al.

in press). Copepod nauplii were generally more common in early May than rotifers. which increased in abundance in July. Adult cyclopoids are a preferred prey of larval perch and alewife (Post and McQueen 1988; Mills et al. 1995), but even at their peak. they accounted for less than 30% of the zooplankton assemblage at both clusters during all five years of study. The lack of suitable sized prey for newly hatched larval fish in early June 2000 -2003 may be influencing their growth and survival. However. three size classes of larval yellow perch selected adult copepods in laboratory experiments and experienced good growth when doing so (Graeb et al. in press). Because adult copepods made up 20-60 % of the zooplankton assemblage in early summer 2002, and 20-90% through mid-July 2003. species composition is likely not a limiting factor for larval fish recruitment when zooplankton densities are as low as those currently found in the field.

Several exotic zooplankton species may also impact the ecology of nearshore waters. The most recent exotic to enter Lake Michigan. *Cercopagis pengoi*, has added another link to the already complex food web. Because the 1999 invasion was relatively recent, more data are necessary to understand the role it will play in the nearshore community. Juvenile alewife do feed on *C. pengoi* (Charlebois et al. 2001), but the importance of it as food for fish or as a zooplankton predator remains unclear. However. a related genus. *Bythotrephes longimanus*, is consumed by yellow perch (Schneeberger 1991) and alewife, which are found at both sampling clusters, as well as by rock bass and lake trout which are found at the artificial reef. The non-digestible rigid spine of *B. longimanus*, makes them difficult to consume for larval fish and may possibly damage the digestive tract of fish. *C. pengoi* has a longer tail spine than *B. longimanus* and thus could have a similar negative effect on fish. A second possible impact of *B. longimanus* is as a competitor with YOY native fish on daphnid populations (Schneeberger 1991).

Veligers, the larval stage of exotic zebra mussels, occurred in relatively high densities during zooplankton sampling in 2000, and especially at the south cluster during 2002 and 2003. Because veligers remain planktonic for 5-35 days, typically feeding on blue-green algae, small green algae, and bacteria ranging from 1-4 μm in diameter (Sprung 1993). there is the possibility of a reduction in small prey available to zooplankton. However. veligers likely do not have the same effect as adult zebra mussels, which reduce phytoplankton stock >1100 times more than veligers (MacIsaac et al. 1992). Low zooplankton densities at the south cluster in 2002 and 2003 were likely not influenced by veligers because zooplankton populations were at very low levels even before veliger densities spiked. Zooplankton densities at the north cluster also were not likely affected by veligers because veliger populations also were at very low levels. Therefore, it appears that zebra mussel veligers are not limiting larval fish recruitment from the bottom up as a grazing planktivore. In addition. veligers do not appear to be preferred prey for larval fish even when they occur in high densities. Veligers have been found in the diets of YOY alewife and rainbow smelt. but contribute less than 0.1 % of the diet (Mills et al. 1995).

Although larval yellow perch and alewife densities differed between clusters. total densities for both species were higher than for other larval fishes collected during 2000 – 2003. These two species also dominated historical larval fish catches at N2 during 1990 - 1997 in a related project, F-123-R (Robillard et al. 1999). however current larval fish densities in both clusters are low (< 8 fish/100m^3) compared to the late 1980s (>25 fish/100m^3). The short term data sets at both clusters lack the temporal variability necessary to determine why these important fish species are occurring in low densities. Collection of larval fish concurrently with other abiotic and biotic data for a period of 5 - 10 years is necessary to identify important variables that may be affecting both the spatial and temporal patterns of these fish species.

Along with changes in density, species composition of larval fish also exhibited monthly and yearly differences across clusters. For example, at the north cluster, alewife comprised a smaller portion of the catch in 2002 and 2003 than in prior years, and cyprinids were more common during 2002 compared to 2001 and 2003. There was a large peak in alewife density during July 2002 at the south cluster; densities were much lower in 2003. It is still unclear what is driving these interannual variations in larval fish composition. Shifts in composition within each cluster suggest that larger scale factors, such as spring warming, water chemistry, predation, or primary productivity levels, may be important.

There are many factors that could influence changes in larval fish density and composition. Yellow perch hatch in late spring, and the rate of spring warming for water temperatures can greatly affect the time of emergence and success of post-hatch larvae. For example, timing of larval yellow perch peak abundance varied between the south and north clusters which warmed at different rates. In 2001, mid-May water temperatures at the south cluster were 6°C warmer than in the north cluster, but very few yellow perch larvae were found in the south cluster. Yellow perch generally migrate to the pelagic zone after hatching (Post and McQueen 1988). Because south temperatures warmed so quickly in 2001, it may be possible that the majority of yellow perch had hatched and already migrated offshore prior to our larval fish sampling. This may also be the case for 2003, because no larval yellow perch were collected after early June. Conversely, spring temperatures warmed more slowly during 2002 in the south, and yellow perch larvae were found through early July at both clusters. Alewife densities increased during late June and July in both clusters because they hatch later in midsummer (Gopalan et al. 1998), whereas larval yellow perch densities decrease later in the season due to their earlier hatching dates and ontogenetic offshore migrations (Post and McQueen 1988).

Peak larval fish abundances were generally observed earlier in the south cluster compared to the north cluster. An advantage for larval fish hatching earlier in the south due to the warmer spring temperatures is an extended feeding and growth period during the first summer (Letcher et al. 1997). These fish should be larger and more successful at surviving the first winter (Ludsin and DeVries 1997). However, early hatching is not an advantage if hatching occurs during times of insufficient prey availability and/or high predator densities. Low zooplankton abundances, with very few or no peaks, in May and June 2000 – 2003 at both clusters likely created a mismatch between zooplankton and fish larvae which resulted in reduced growth and survival for early spawned fish such as yellow perch, cyprinids, and smelt. This mismatch could be another explanation in addition to offshore migration for the extremely low densities of larval yellow perch in the south cluster during 2001 and 2003. South zooplankton densities in May 2001 were the lowest of all four years of study. Therefore, if the yellow perch did spawn earlier in 2001 due to the fast spring warm up, food resources would have been extremely limited for the young perch and survival would likely have been very low.

Alewife densities were generally higher than perch during July in both clusters, when rotifers were increasing in abundance. Alewives can feed more efficiently on small zooplankton such as these because of their ability to switch to filter feeding (Crowder et al. 1987). Our ongoing analysis of larval fish age structure and growth through otolith processing, and larval fish feeding experiments will help determine whether poor growth and ultimately poor survival occurred differently from north to south and how this may be influenced by temperature and prey availability.

Densities of benthic invertebrates found in the sediments within each cluster were similar during 2000 – 2003, but differed greatly between clusters. Benthic invertebrate densities in Lake Michigan waters declined between 1980 and 1993, likely due to decreased phosphorus inputs and the invasion of zebra mussels (Nalepa et al. 1998). Our densities were very similar to those obtained in a recent study in shallow waters (< 7.5 m) of Lake Michigan (Fullerton et al. 1998). However, these densities were very low compared to those in 1980 – 1993 survey (Nalepa et al. 1998). Benthic invertebrates are important to the function of the aquatic community because they act as a benthic-pelagic link as prey for many fish species (Covich et al. 1999). Many YOY fish such as yellow perch, spottail shiner, and trout-perch *Percopsis omiscomaycus* rely on benthic invertebrates as primary or secondary food sources, especially when they reach 30 mm (Gerking 1994; Gopalan et al. 1998). For example, in both Lake Erie and Lake Michigan, yellow perch diets consisted primarily of invertebrates during midsummer declines in zooplankton (Post and McQueen 1994; Roseman et al. 1996).

The high total benthic invertebrate density at the north cluster is not really an advantage to YOY fish compared to the south cluster, because zebra mussels are the primary contributor to these density levels. Adult zebra mussels are not preferred prey of young of the year fish because of their difficulty to digest them (Morrison et al. 1997). Continued decreases in other benthic invertebrate taxa without a commensurate increase in zooplankton abundance, could negatively impact recruitment of nearshore fishes. If this scenario continues, long-term shifts in the fish community could result.

Although invertebrate densities have changed, species composition has remained similar in soft sediments of Lake Michigan's southwestern basin. Chironomids and oligochaetes were the most abundant invertebrates at the south cluster, just as they were in other studies (Fullerton et al. 1998; Nalepa et al. 1998), and in the north cluster, with the exception of zebra mussels. Also, it is important to note that the benthic invertebrate densities reported for this study are from soft sediments only, and do not include those taxa that inhabit complex structure. It is therefore very possible that our results under estimate the actual number of benthic organisms available as prey to fish. Regardless, apparent low benthic invertebrate densities need to be further evaluated before relationships to fish recruitment can be understood.

Artificial Reef

Data collected in 1999 before the artificial reef was constructed indicate that the reef and reference sites were comparable in abiotic and biotic characteristics. Because these sites were similar before reef construction, comparisons after reef construction can be made to determine the types of changes resulting from the presence of the artificial reef.

Overall species diversity of fish caught in gillnets at the artificial reef site was higher than at the reference site and has increased since 2000. This was also true for dive observations from 2000 to 2003. Round goby continued to be the primary species observed during transect swims of the reference site. Gobies were also the only fish seen in pre-reef swims at the artificial reef site, but seven different species have been observed since reef construction. Round goby percent coverage decreased after the arrival of smallmouth bass, which was likely due to predator avoidance.

Significantly fewer smallmouth bass were caught in gillnets and observed during dives at the reference site 2000 – 2002 compared to the artificial reef. At the artificial reef yearling smallmouth bass were only a small fraction of all smallmouth bass observed, probably because adults prefer deeper habitats and migrate to shallow water only during spawning, whereas juvenile smallmouth bass stay nearshore (Cole and Moring 1997; Dong and DeAngelis 1998). Yearling smallmouth bass that do appear on the artificial reef are likely immigrants from nearby spawning and rearing sites, because no adults have yet to be observed nesting at the artificial reef. Rock bass were also more strongly attracted to the artificial reef site than the reference site. These dive and gillnet data tend to indicate that the reef is attracting more smallmouth bass and other fishes than the reference area. A prime example of this is the observation of juvenile largemouth bass on the reef for the first time during the 2002 sampling season. However, when looking at the species composition of gillnets catches as a whole, there were no significant differences in catch rates between the two sites. The reef appears only to be attracting those species that prefer rocky, complex habitats significantly more than the reference site. Other species, such as yellow perch and freshwater drum, use both locations fairly equally.

Both the numbers of smallmouth bass observed and the seasonal timing of artificial reef use from year to year has not varied widely. The first observation of adult smallmouth bass on the artificial reef during dive transects has varied by only 17 days among years. The appearance of smallmouth bass at the artificial reef appears to be temperature driven. Smallmouth bass spawn at traditional locations during temperatures of 15-18.3°C (Armour 1993), and then appear to migrate to the reef when nest guarding is complete and water temperatures warm above 22°C. The first sighting of adult smallmouth bass at the artificial reef site has consistently been on the first sampling date when water surface temperatures were above 22°C. except during 2003. One smallmouth bass was observed during the transect swim on July 14, 2003 when surface temperature was 17.2°C. Smallmouth bass were also never caught in gillnets before water temperatures reached 22°C. Based on dive observations and gillnet data, it appears that smallmouth bass remain at the reef until early October when temperatures decline to 14 - 17°C. This coincides with data from Langhust and Schoenike (1990) who observed that age-2 and older smallmouth bass initiated winter migrations when temperatures fell below 16°C. Observations from fall 2003 will help determine whether this pattern is consistent from year to year. It is not known to where the smallmouth bass migrate once they leave the artificial reef.

Yellow perch were observed during dives at the artificial reef site more frequently in 2001-2003 than 2000 and were first caught in gillnets during 2001. Addition of smaller mesh panels to the gillnets in 2002 resulted in much larger catches of yellow perch at both the reference and artificial reef sites than in previous years. Catches of yellow perch declined at both sites during all years when temperatures rose above 22°C. Although 75 yellow perch were collected in gillnets at the artificial reef site on June 24, 2002, only three were observed during the dive transect of the reef on that date. This may indicate that yellow perch do not use the reef as long term habitat, but are mainly transients attracted to the reef for food or temporary shelter. However, the 2002 and 2003 data did show that yellow perch were present at both the reference and artificial reef sites more frequently and at higher abundances than in previous years. This may be due to sampling bias or year to year variation based on water temperatures or prey availability.

Rock bass presence also increased during late summer 2002 compared to previous years. Rock bass first appeared in mid-June and were usually observed close to the rock structure. It is unclear how this species will utilize the artificial reef in the long term. Juvenile largemouth bass appeared at the reef in 2002 and have not been observed at the reference site. They were usually swimming singly or in small groups close to the rocks. The size range of these fish indicated that they were sub-adult fish. Largemouth bass juveniles have not been observed to date during 2003. It is unknown why these fish were seen in 2002 and not in other years, or whether these fish will continue to migrate from the harbors, where they are typically found, to the reef in future years. Factors that may have led to this migration in 2002 could be extreme high temperatures in the harbors or intra-species competition due to high juvenile densities.

The colonization of the reef by invertebrates is still unclear. Rock baskets used in 1999 and 2000 were selecting for species that colonize structurally complex habitats. regardless of the surrounding structure. Clay tiles deployed in 2001 could not be successfully retrieved. Despite large densities of zebra mussel veligers present at the south cluster during 2002 and 2003, densities of adult zebra mussels in the south benthic core samples were very low. Visual observations of the artificial reef confirmed that some juvenile zebra mussels colonized the artificial reef during fall 2000, but few zebra mussels were present on the reef in 2001 - 2003. This suggests that zebra mussels may not readily persist at the artificial reef. This may be due to a combination of the strong wave action during storms and the predominantly flat, smooth surface of most of the reef rock. Zebra mussels are known to prefer substrates with rough, rather than smooth texture (Marsden and Lansky 2000). More efficient and practical means of sampling the benthic community of the reef are needed to understand how and what benthic invertebrates colonize rock structures in nearshore Lake Michigan.

The five year data set from this study indicated that smallmouth bass and rock bass use was greater at the artificial reef than at the reference site, whereas catch rates for the fish community as a whole did not differ between the two sites. Continued observations at both the artificial reef and reference sites are needed to determine whether smallmouth bass, yellow perch, rock bass, largemouth bass, etc. benefit from the artificial reef through increased production or if they are only attracted to the structure for either food, shelter, or both. It is also important to continue to monitor the maturation of the artificial reef in relation to the entire aquatic community to improve our understanding of artificial reef dynamics in large freshwater systems.

Conclusion

Current management strategies for Lake Michigan focus on nearshore waters as a contiguous unit despite many habitat differences. Therefore, it is important to continue to investigate how ecological conditions vary temporally and within smaller spatial scales of the nearshore zone, and the effects these differences (e.g., temperature and zooplankton) may have on growth, survival, and species composition of the entire nearshore fish assemblage.

Preliminary and continuing analysis of data from Segments 1-5, showed that temperature and zooplankton are two factors that appear to contribute to the survival of nearshore fish early in their life. Continued monitoring of larval and juvenile fishes along with abiotic and biotic variables that may affect their success is needed to determine 1) what mechanisms play a role in regulating recruitment in Illinois nearshore waters, 2) the extent of recruitment variability across years and between clusters, and increase understanding of why these fluctuations occur, and 3) appropriate mechanistic models to predict year-class strength of nearshore fishes to aide managers in making decisions for harvest regulations.

Acknowledgements

We would like to thank M. Kneuer for administrative support. W. Brofka, B. Pientka, A. Jaeger, R. Goralczyk, S. Miehls, A. Thomson and numerous field staff helped to collect, process, and analyze these data.

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Table 1. Summary of sample types and numbers collected at the south sampling cluster (artificial reef-S1 and reference site-S2) during 1999 through August 18, 2003.

	Zooplankton	Benthic Cores	Larval Fish	Gillnets	SCUBA transects
1999	52	27	40	12	4
2000	42	30	28	32	10
2001	20	20	16	28	5
2002	48	32	24	32	15
2003	19	16	16	20	10
Total	**181**	**125**	**124**	**124**	**44**

Table 2. Summary of sample types and numbers collected at the north sampling cluster (sites N1 and N2) during 1999 through August 18, 2003.

	Zooplankton	Benthic Cores	Larval Fish	Bottom Trawl
1999	113	47	36	138
2000	63	32	35	74
2001	33	24	25	53
2002	50	32	31	59
2003	29	16	22	30
Total	**288**	**151**	**129**	**354**

Table 3. Fish counts observed during SCUBA transect sampling at the artificial reef site from 1999- 2003. SMB=smallmouth bass, LMB=largemouth bass, Carp=common carp. Goby=round goby.

Date	Goby	Alewife schools	Carp	Rock bass	SMB adults	SMB juveniles	Yellow Perch	LMB juveniles
6/30/99	15%							
8/3/99	15%							
6/26/00	40%			7			3	
7/25/00	10%		2		30			
8/2/00	5%			4	11	1		
8/28/00	5%			1	11	5		
9/13/00	5%				30	3		
10/3/00					4	1		
6/12/01	10%	7		6			11	
6/28/01	20%	2					2	
8/2/01	10%			45	2	3	6	
5/5/02	15%							
6/24/02	10%	1		1		1	3	
7/16/02	3%			1	11			6
7/30/02	3%			44	29	1		13
8/14/02	3%			20	43		1	16
8/28/02	5%			5	9	1	1	1
9/17/02	1%			1	44			
10/1/02	1%				15			
6/5/03	8%	(1 fish)					1	
6/18/03	4%						3	
7/1/03	8%	4		2			47	
7/14/03	2%	1			1			
7/29/03	2%			1	4			
8/19/03	5%			3	6			

Table 4. Fish counts observed during SCUBA transect sampling at the reference site from 1999- 2003. SMB=smallmouth bass, LMB=largemouth bass, Carp=common carp, Goby=round goby. No data for 6/26/00,10/3/00, and 6/12/01.

Date	Goby	Alewife schools	Carp	Rock bass	SMB adults	SMB juveniles	Yellow Perch	LMB juveniles
6/30/99	15%							
8/3/99	15%							
7/25/00	10%			4	5			
8/2/00	10%							
8/28/00	10%				2			
9/13/00	5%							
6/28/01	5%							
8/2/01	5%	1						
5/5/02	5%							
6/24/02	5%			1			1	
7/16/02	5%	(1 fish)						
7/30/02	5%		1					
8/14/02	1%							
8/28/02	1%							
9/17/02	3%							
10/1/02	1%							
6/18/03	3%							
7/1/03	3%	(1 fish)						
7/14/03	3%							
7/29/03	3%	1+4 fish						
8/19/03	<1%							

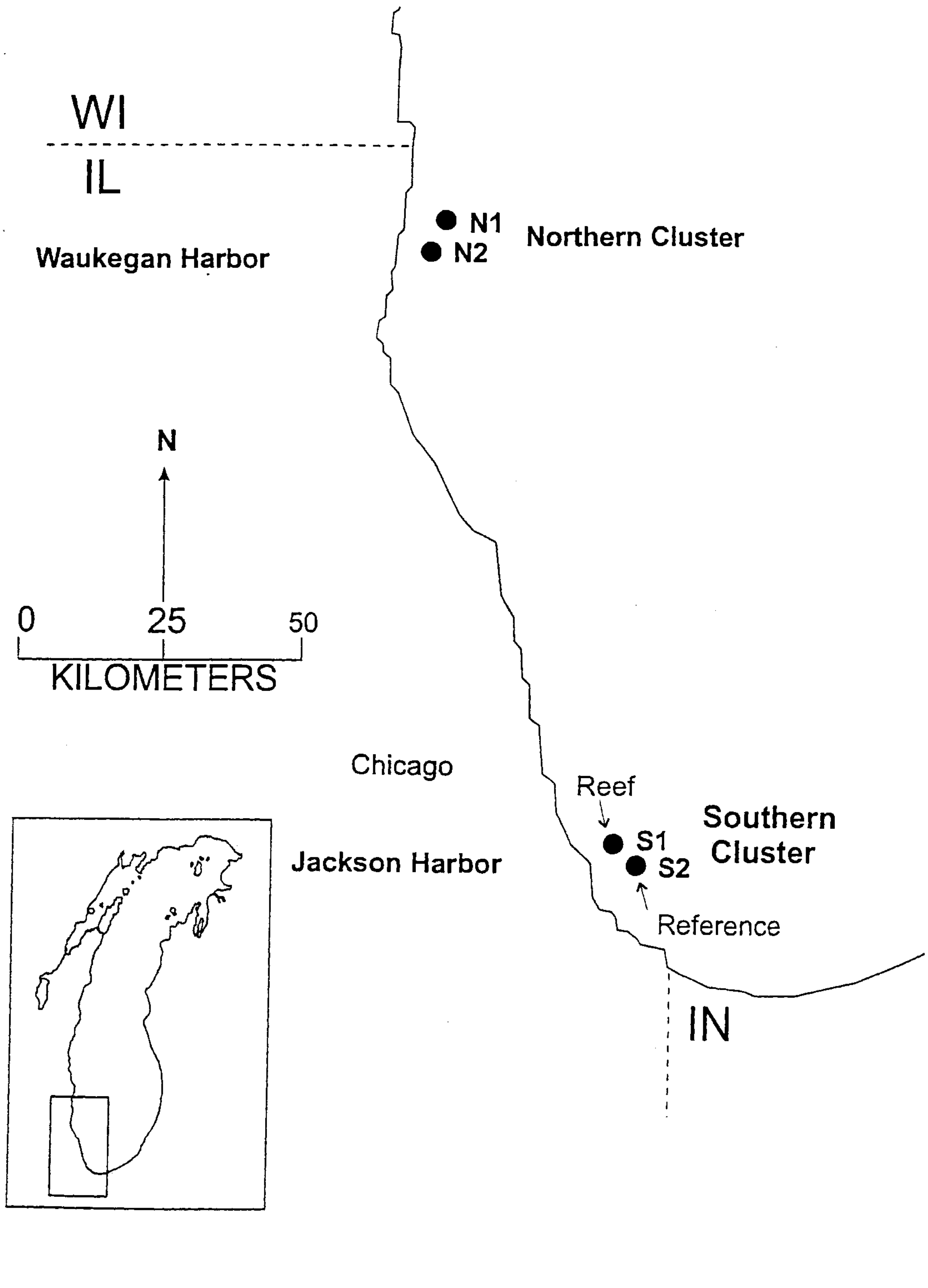


Figure 1. Northern and southern (including artificial reef and reference sites) sampling clusters in the nearshore waters of Lake Michigan.

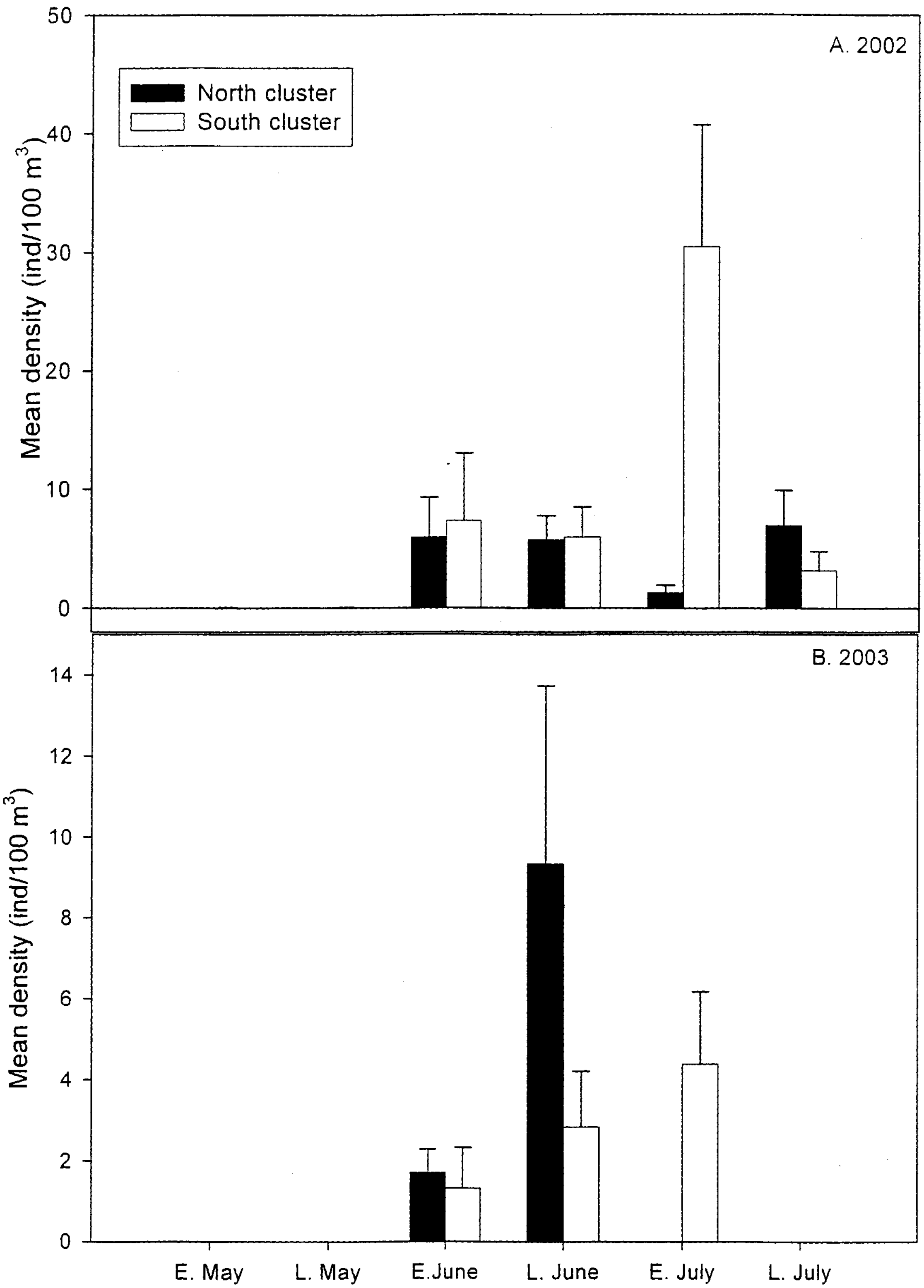


Figure 2. Mean (+ 1 SE) larval fish abundance at both clusters during May – July (A) 2002 and (B) 2003. Note that the y-axis scales vary considerably.

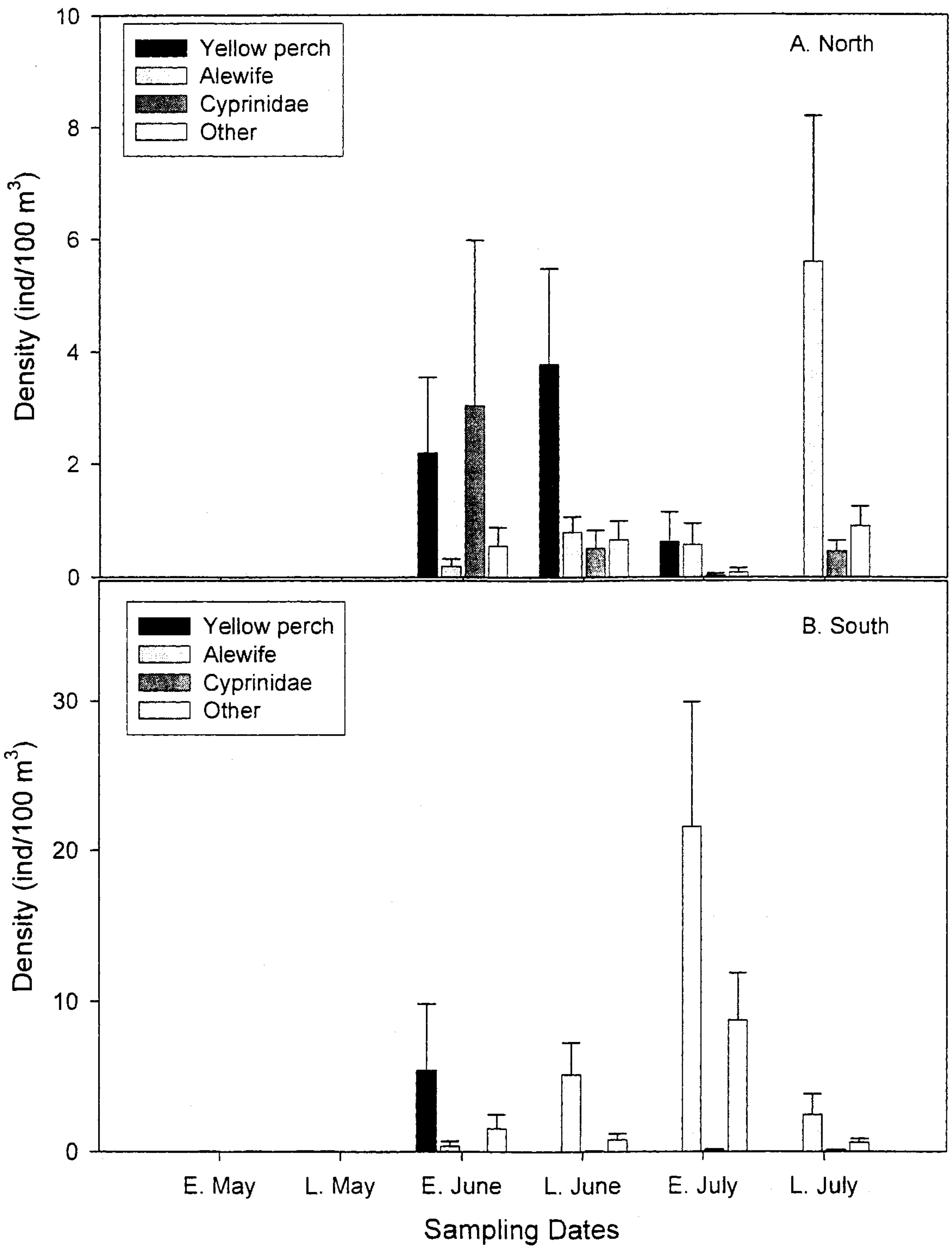


Figure 3. Mean densities (+ 1 SE) of larval yellow perch, alewife, cyprinids and other species at the (A) North and (B) South sampling clusters along the Illinois shoreline of Lake Michigan during May – July 2002.

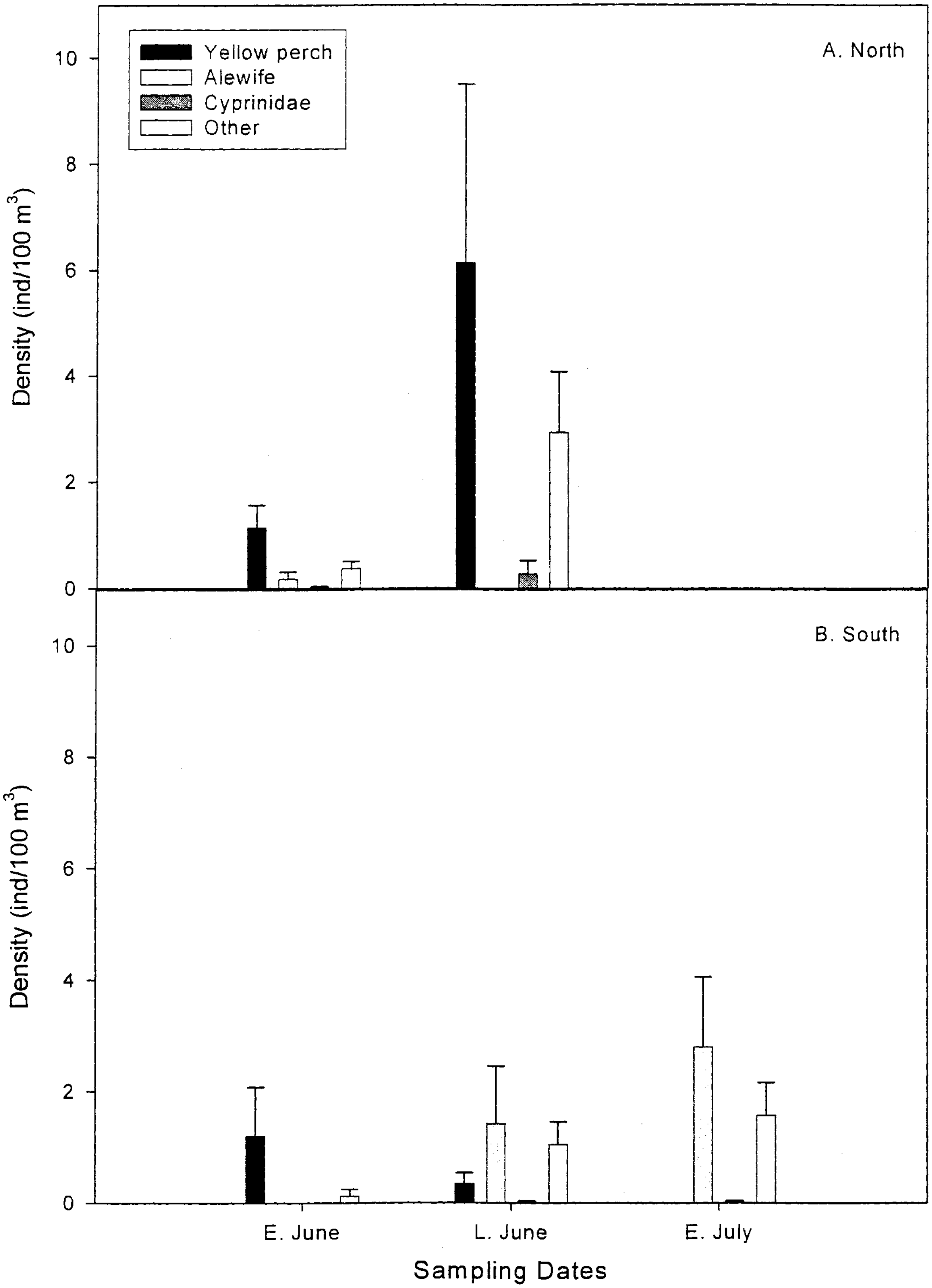


Figure 4. Mean densities (+ 1 SE) of larval yellow perch, alewife, cyprinids and other species at the (A) North and (B) South sampling clusters along the Illinois shoreline of Lake Michigan during June - July, 2003.

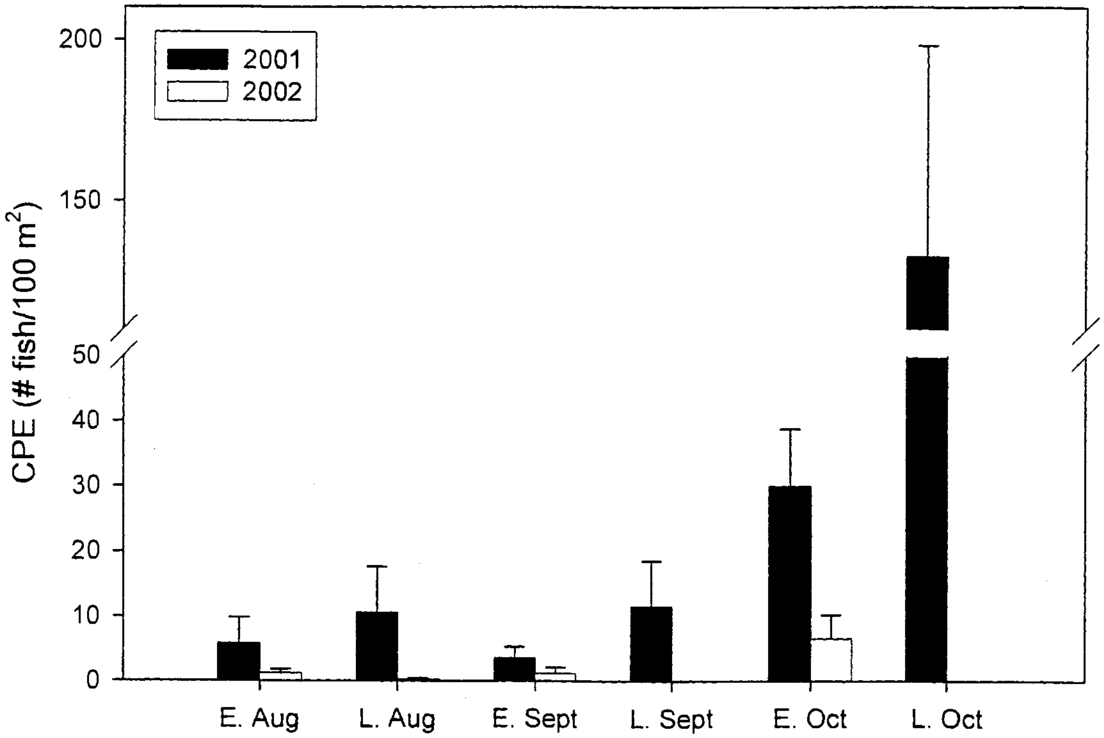


Figure 5. Mean (+ 1 SE) CPE (number of fish/100 m^2 of bottom swept) of all fish collected with a bottom trawl at N2 during 2001 and 2002. E. = early; L. = late.

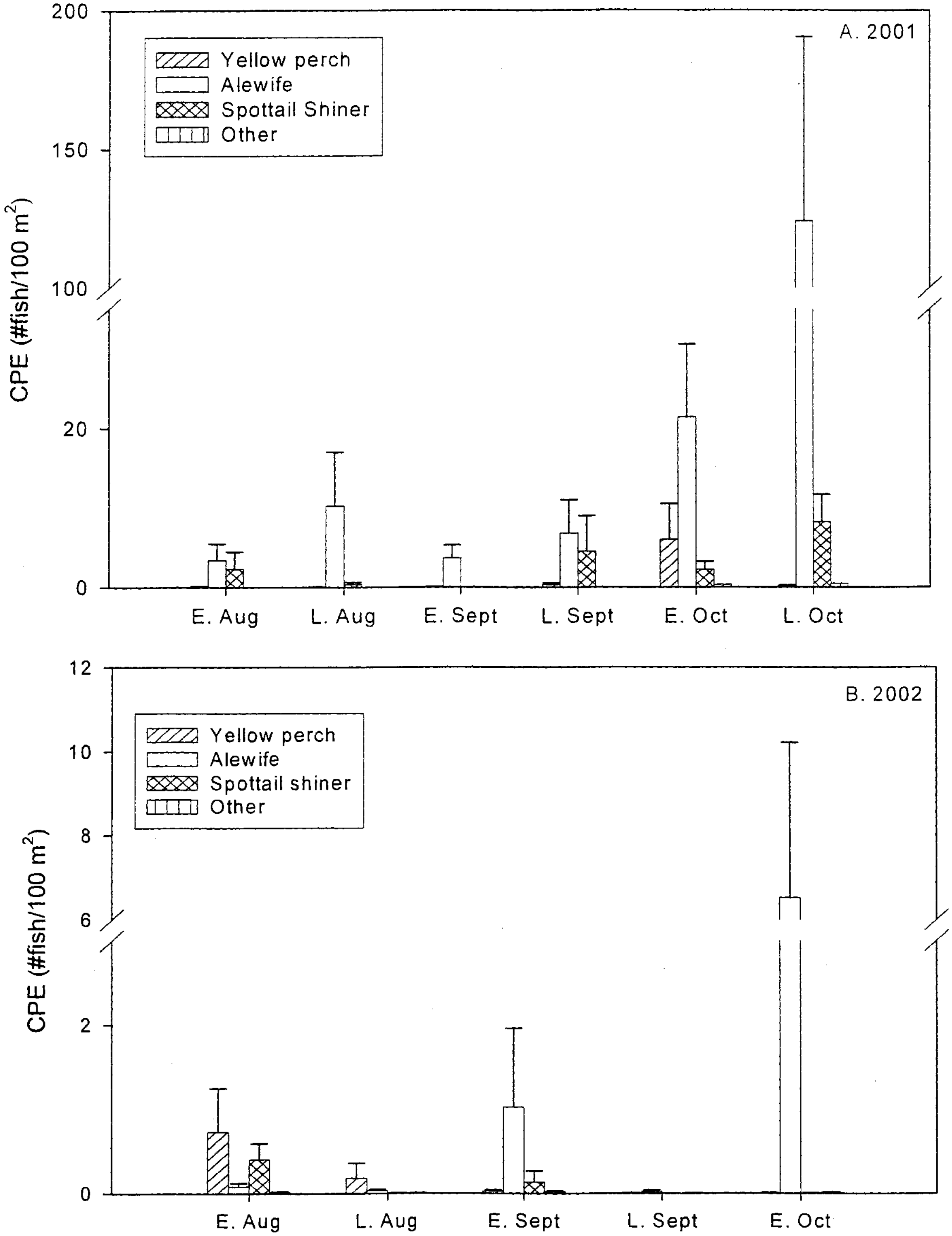
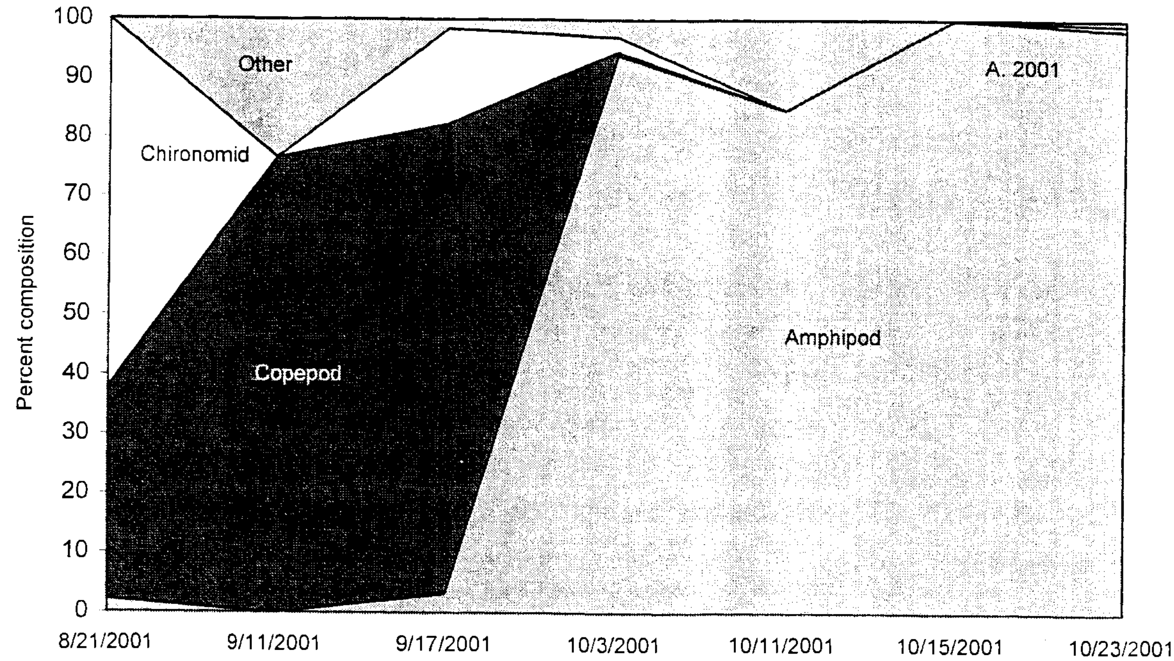


Figure 6. Mean (+ 1SE) CPE (number of fish/100 m^2 of bottom swept) of yellow perch, alewife, spottail shiner, and other species collected with a bottom trawl in the northern cluster during (A) 2001 and (B) 2002. E. = early; L. = late. Note that the y-axis scales vary considerably.



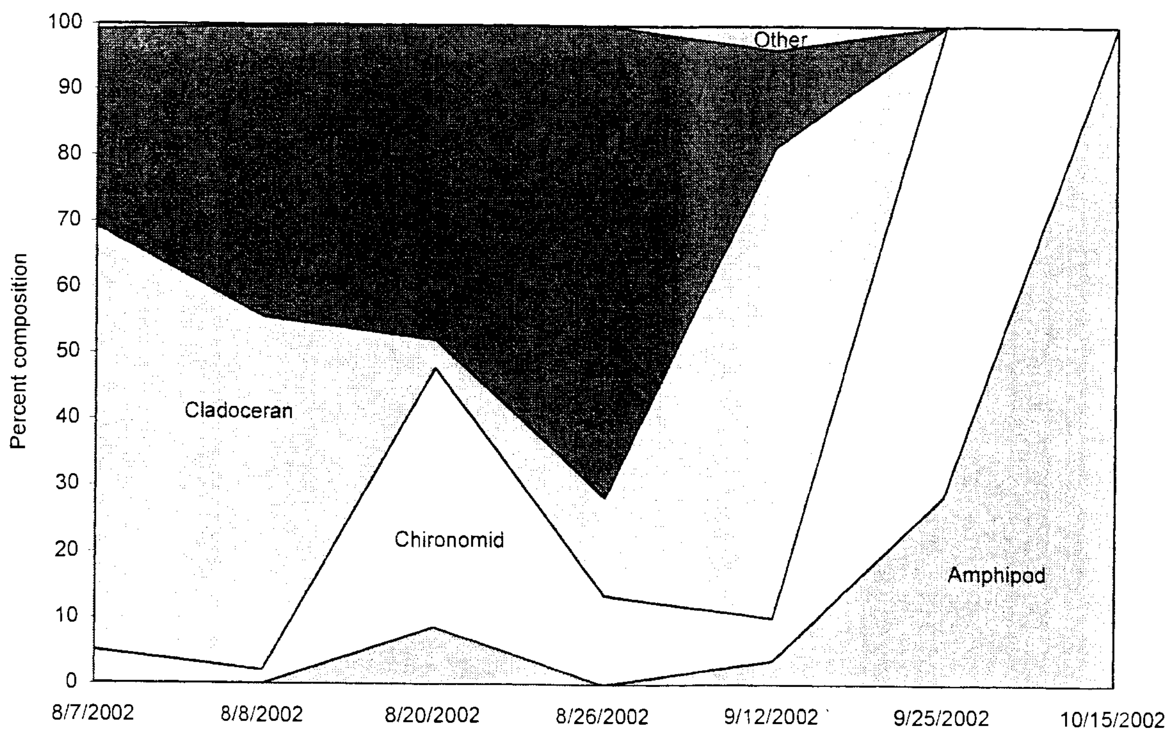


Figure 7. Percent composition by number of items in the diets of YOY yellow perch collected in bottom trawls at the northern cluster during (A) 2001 and (B) 2002.

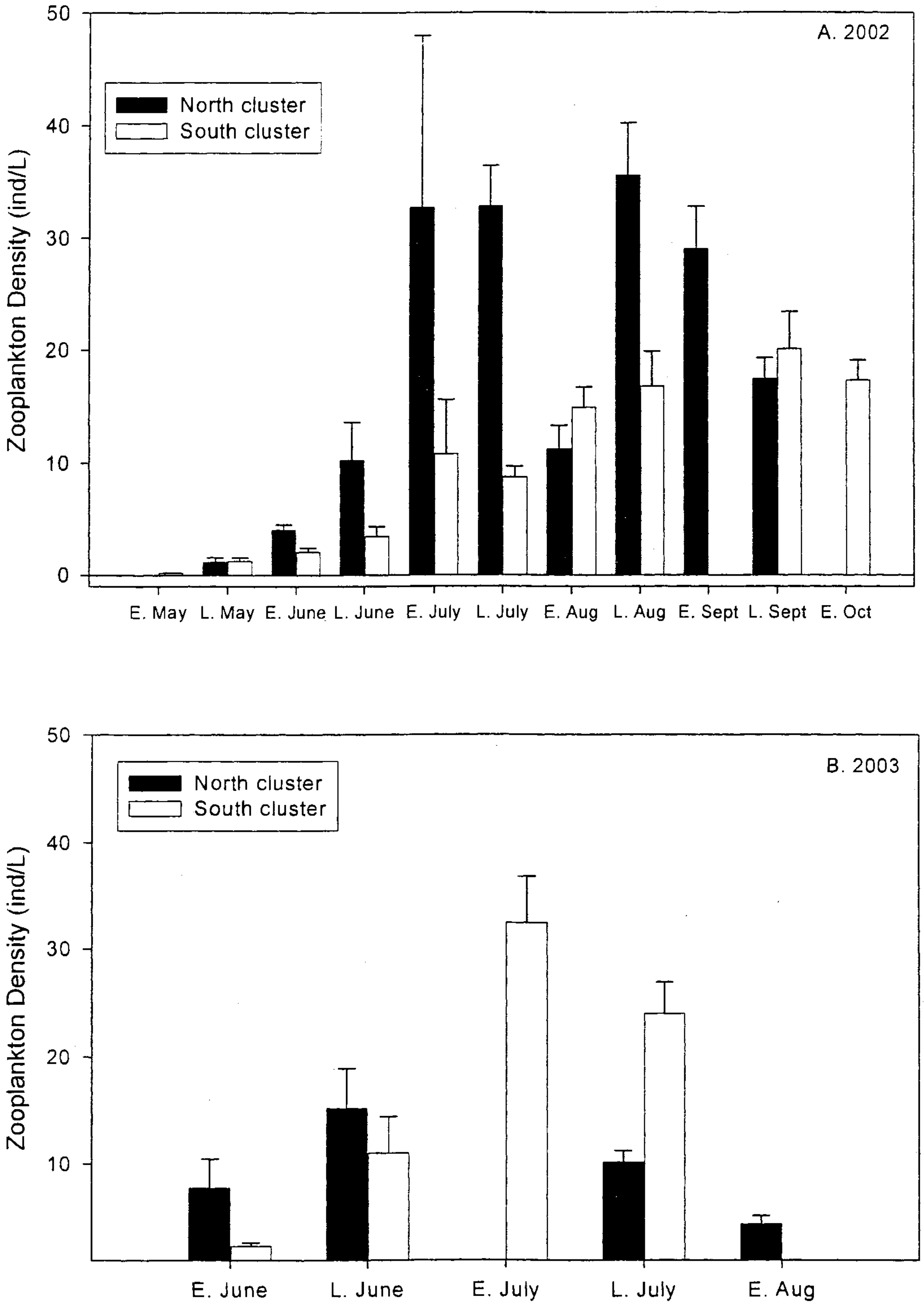


Figure 8. Total zooplankton density (mean + 1SE) during (A) 2002 and (B) 2003 at the north and south clusters in the nearshore waters of Lake Michigan. E. = early; L.= late.

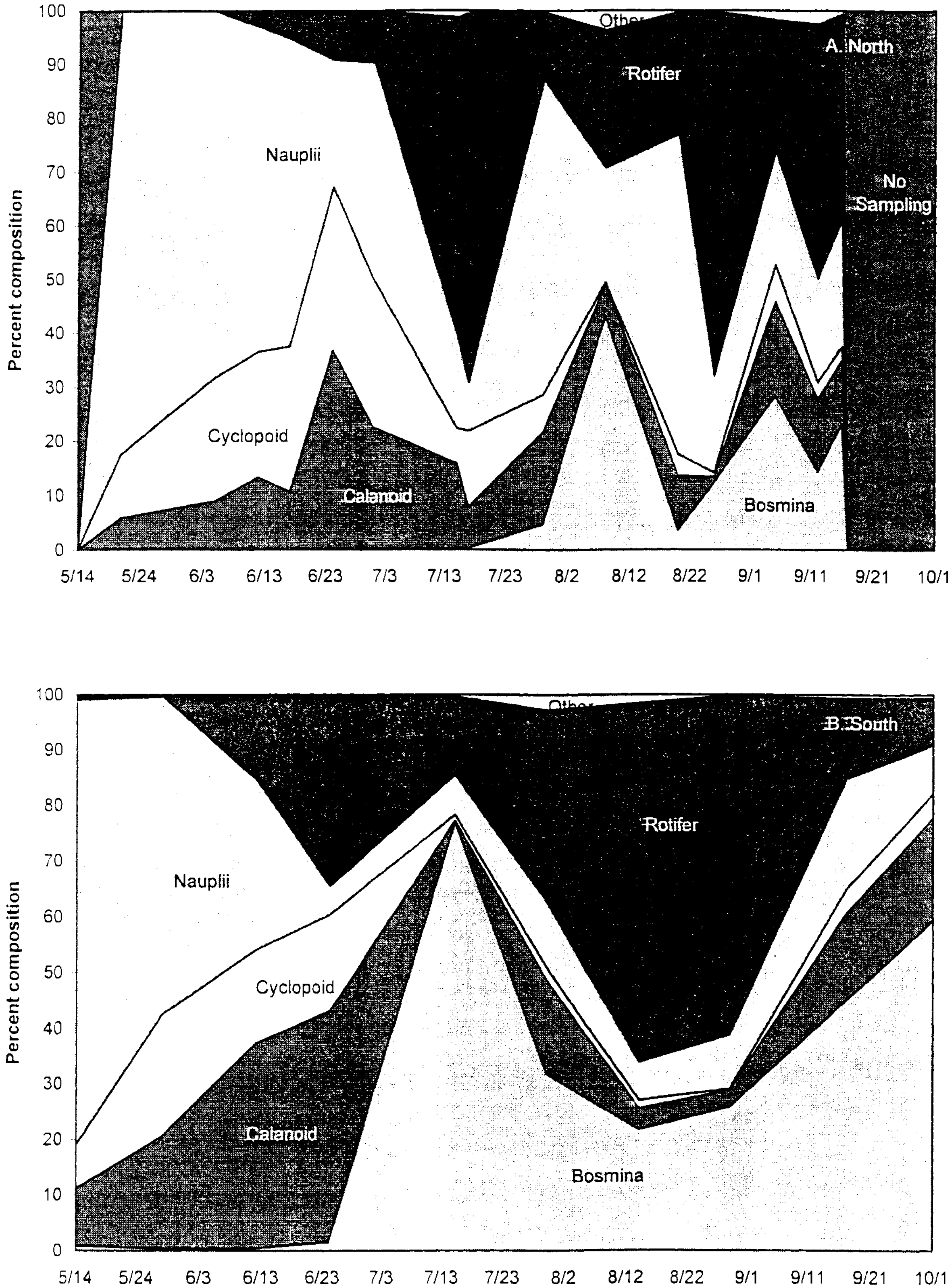


Figure 9. Percent composition of the nearshore zooplankton assemblage at the (A) northern and (B) southern clusters in Illinois waters of Lake Michigan during the 2002 sampling season.

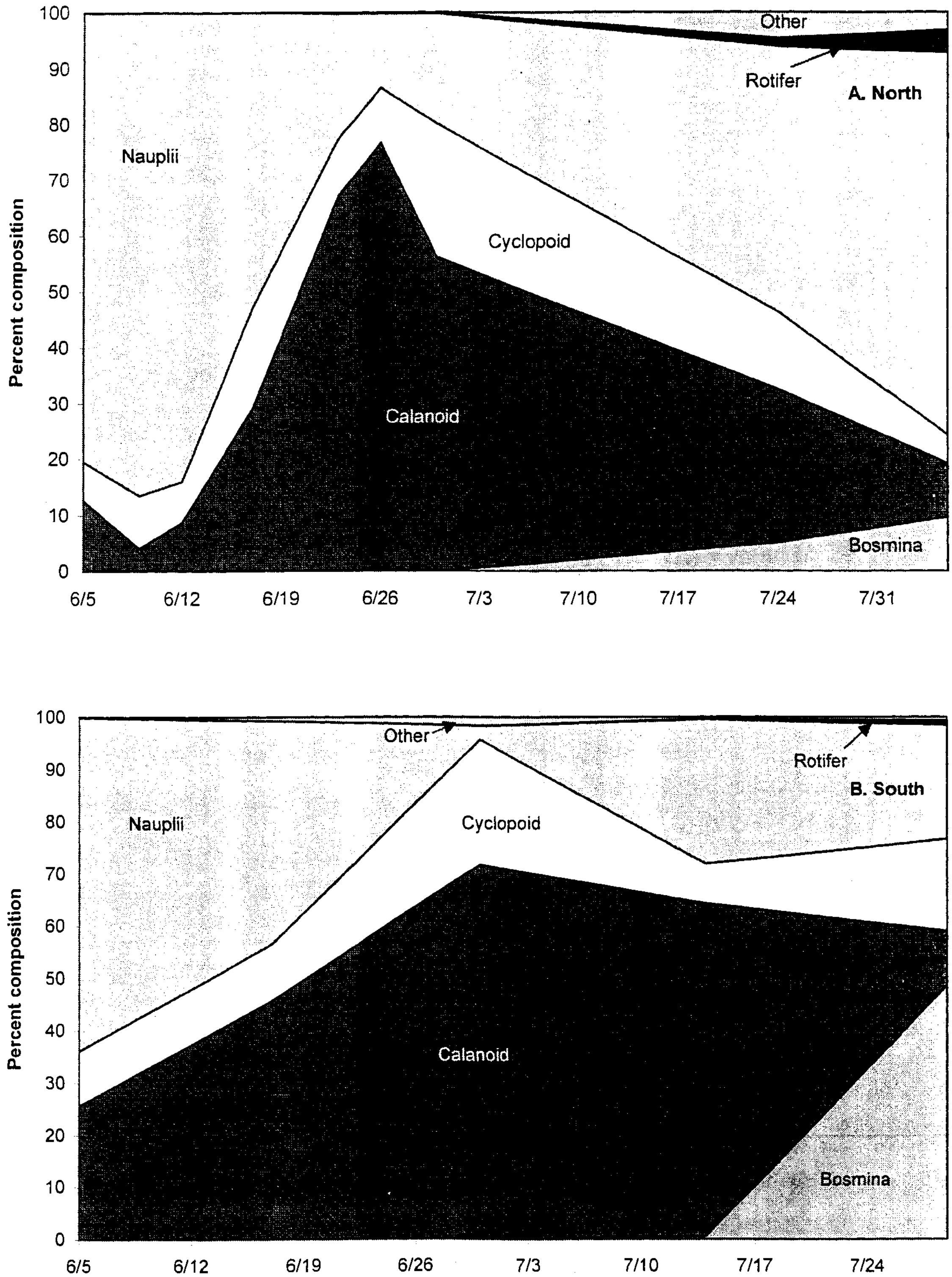


Figure 10. Percent composition of the nearshore zooplankton assemblage at the (A) northern and (B) southern clusters in Illinois waters of Lake Michigan during the early 2003 sampling season.

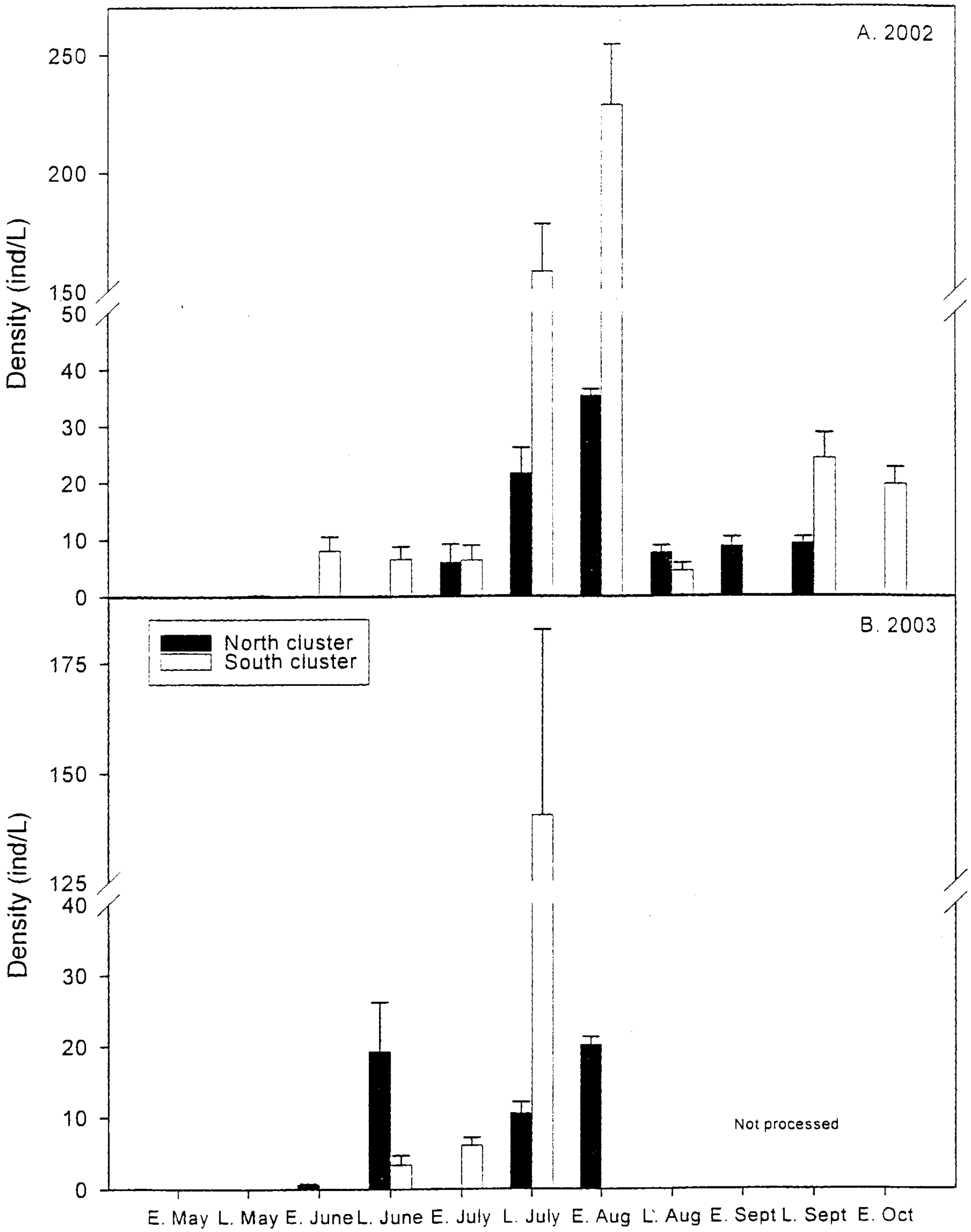


Figure 11. Zebra mussel veliger density (mean +1 SE) at northern and southern clusters in the nearshore waters of Lake Michigan during (A) 2002 and (B) June through early August 2003. E. = early; L.= late.

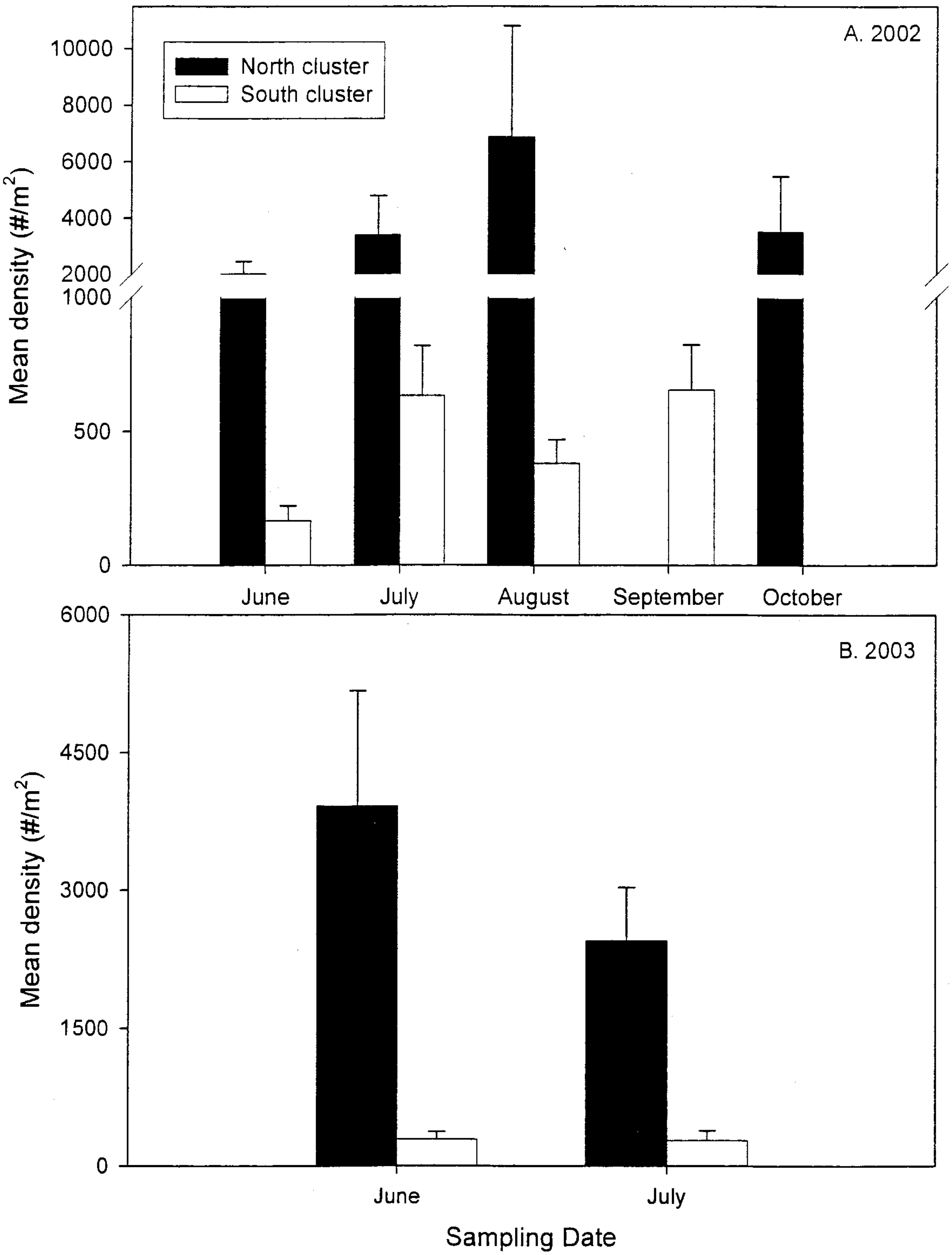


Figure 12. Mean density (+1 SE) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the north and south sampling clusters in the Illinois waters of Lake Michigan during (A) July – October, 2002 and (B) June and July, 2003.

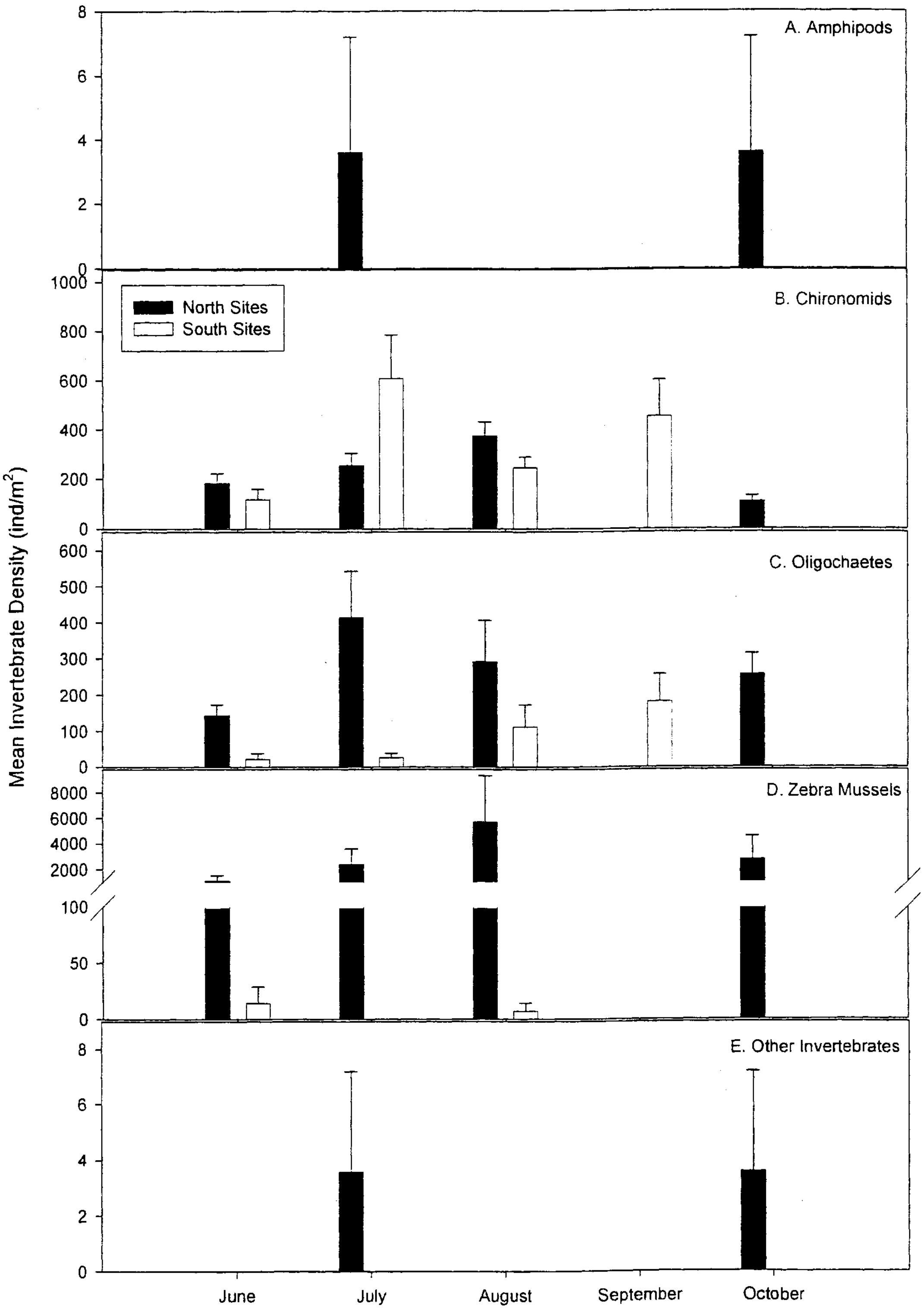


Figure 13. Mean density (+ 1 SE) of (A) amphipods, (B) chironomids, (C) oligochaetes, (D) zebra mussels and (E) other benthic invertebrates sampled during June – October 2002. Note that the y-axis scales vary considerably.

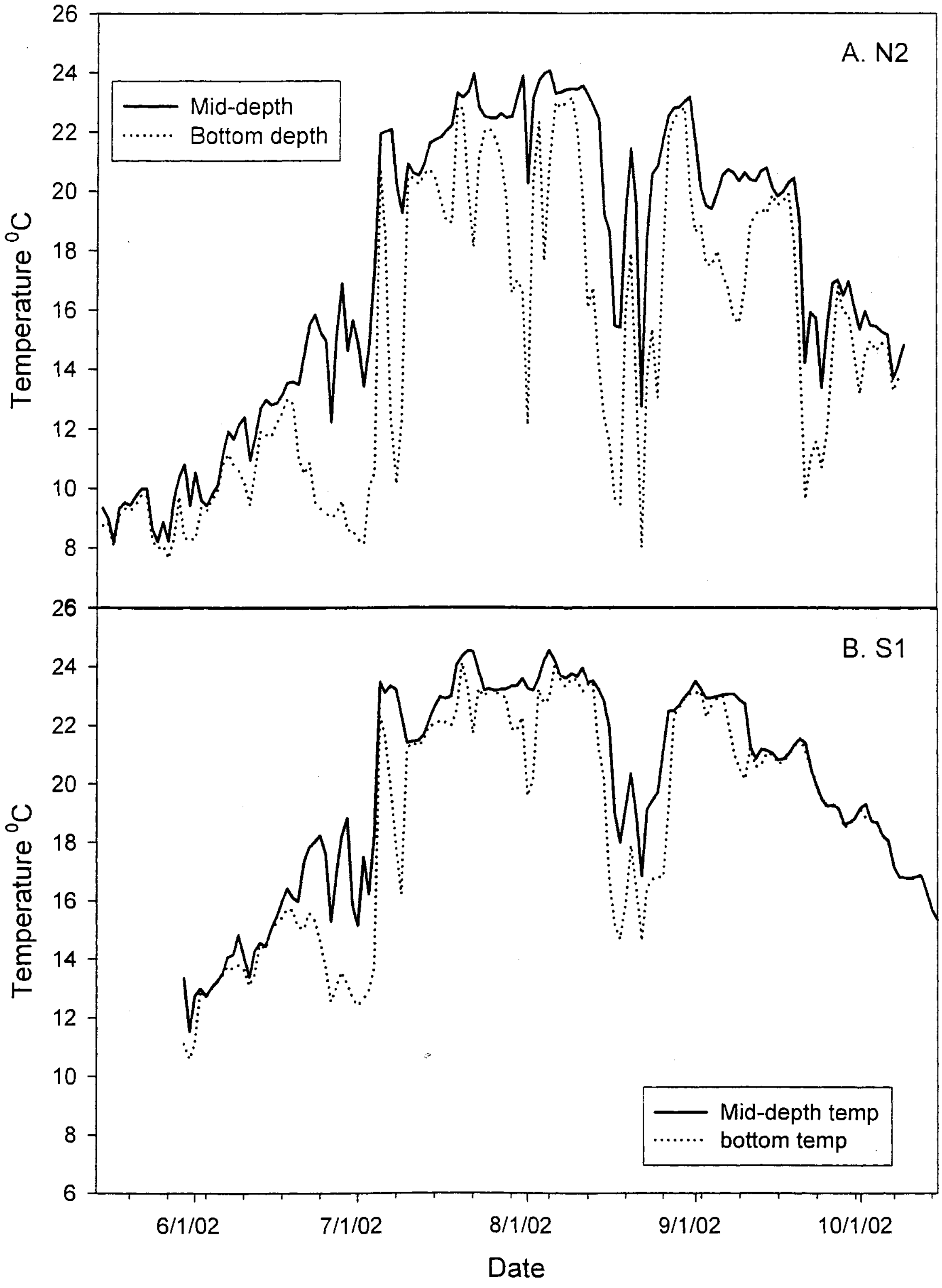


Figure 14. Mean temperature recorded from thermal loggers at the bottom and mid-depth during 2002 at the (A) northern - N2 and (B) southern cluster - S1.

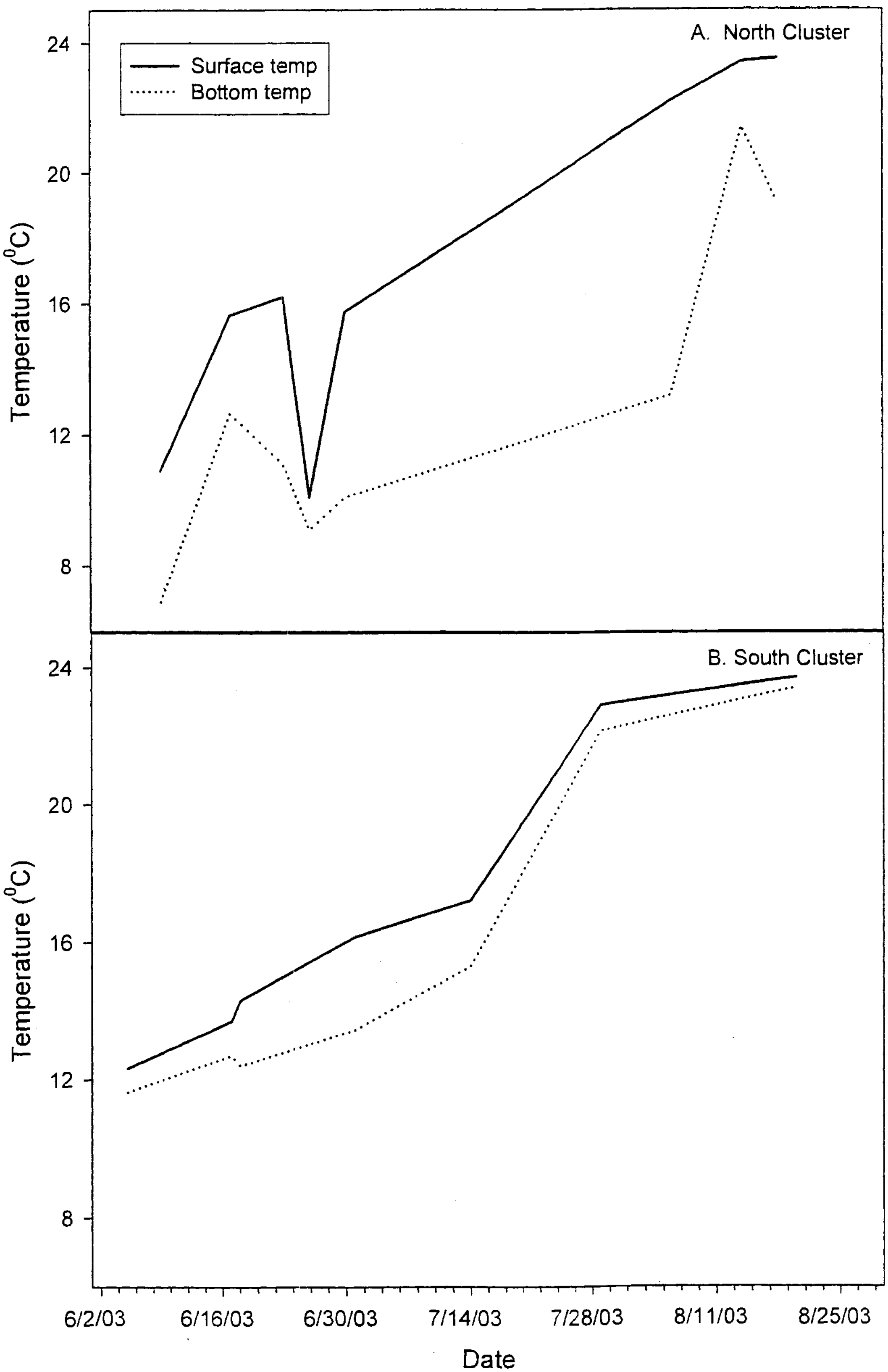


Figure 15. Mean surface and bottom temperature recorded at the (A) northern and (B) southern sampling sites during June – August, 2003.

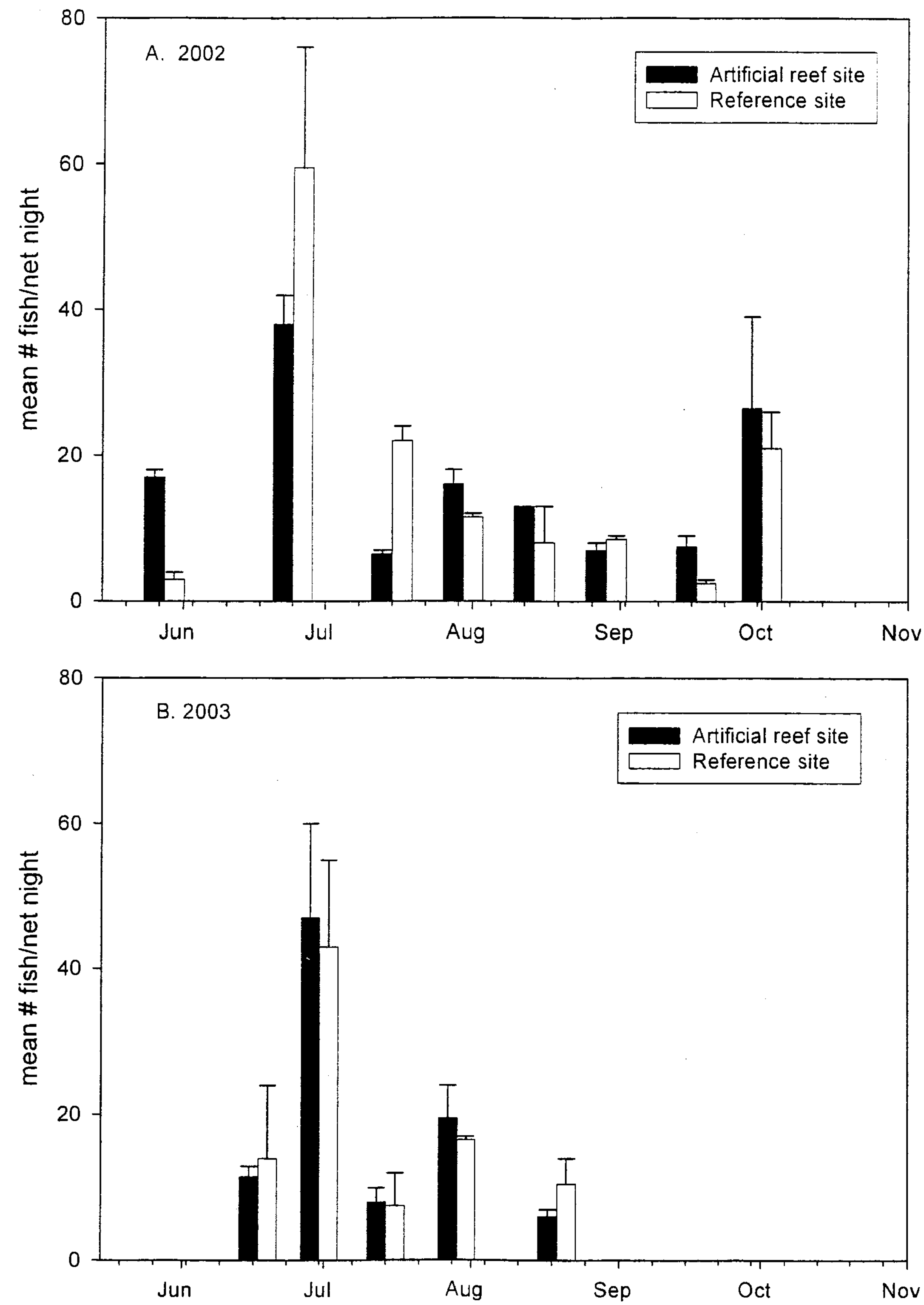


Figure 16. Mean number of fish (+ 1 SE) caught per net-night in gillnets at the artificial reef and reference sites during (A) 2002 and (B) 2003.

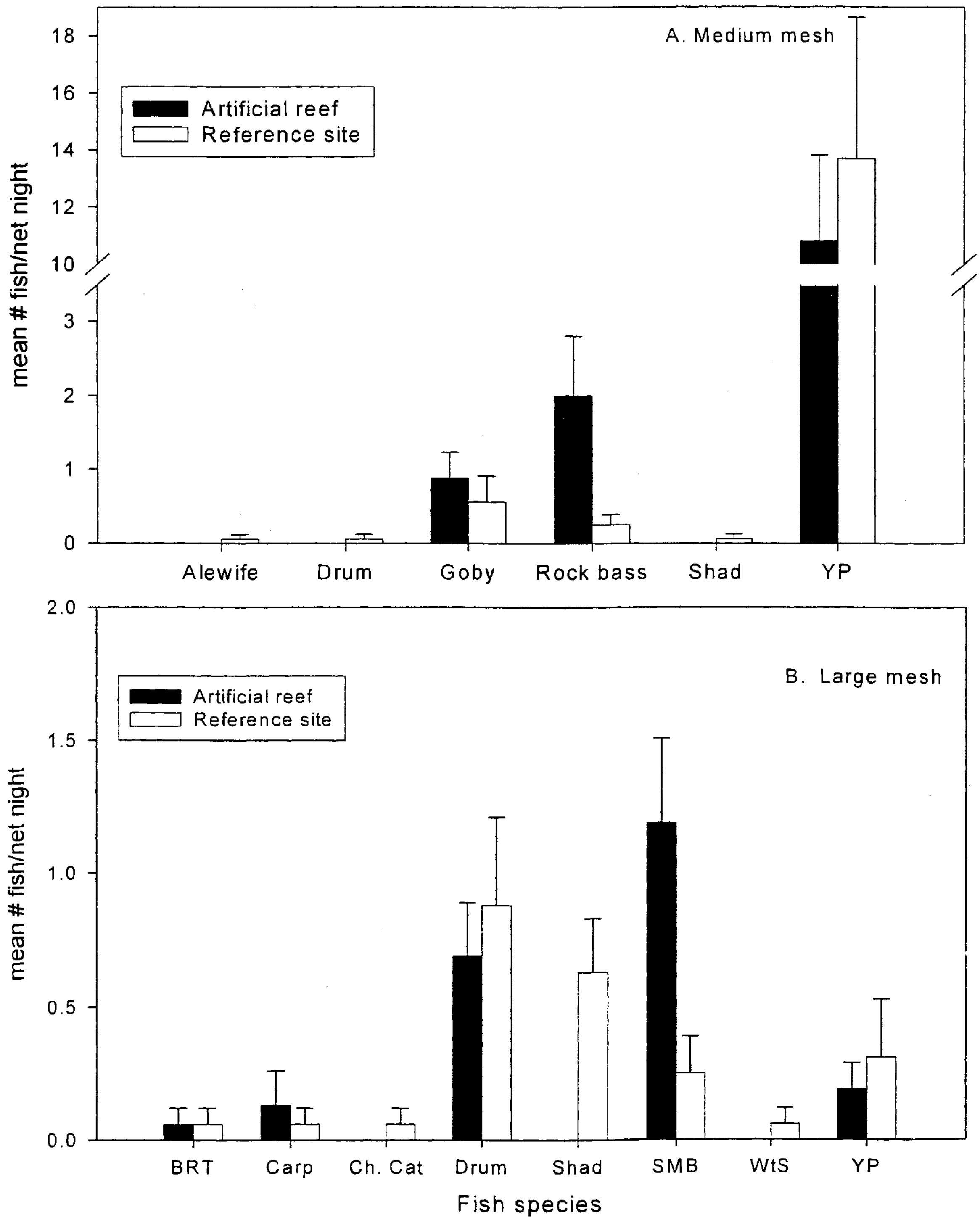


Figure 17. Annual mean number of individual fish species (+ 1 SE) caught in (A) medium mesh gillnet panels (5.1 and 7.6 cm stretch) and (B) large mesh gillnet panels (10.2 and 11.5 cm stretch) at the artificial reef and reference sites during 2002. Goby = round goby; Shad = gizzard shad; YP = yellow perch; BRT = brown trout; Ch. cat = channel catfish; Drum = freshwater drum; LKT = lake trout; SMB = smallmouth bass; WtS = white sucker.

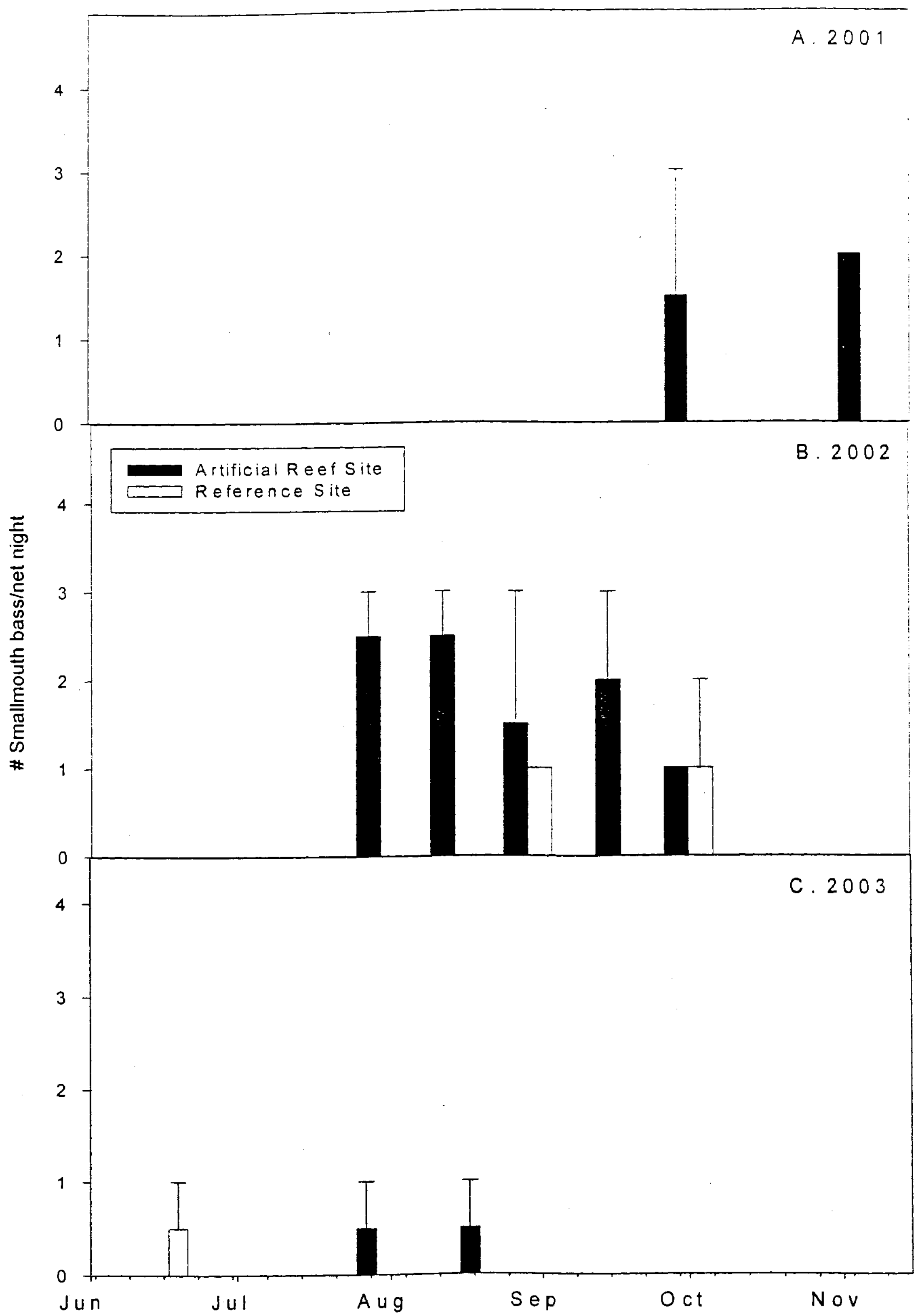


Figure 18. Mean number (+ 1 SE) of smallmouth bass caught per net-night in large mesh gillnet panels (10.2 and 11.5 cm stretch) at the artificial reef and reference sites during 2001 - 2003.

Appendix A. Cost Summary for 2002 - 2003

Segment 7

Study 101 Quantify the abundance, taxonomic composition, and growth of larval fish
- Job 1: Quantify abundance and taxonomic composition of larval fish $13.000
- Job 2: Quantify growth of larval fishes $ 7.000
- Job 3: Data analysis and report preparation $ 3.000

Study 102 Quantify the abundance, composition, and growth of YOY fishes
- Job 1: Quantify abundance, growth, and composition of YOY fishes $10.000
- Job 2: Diet analysis of nearshore YOY fishes $ 7,000
- Job 3: Data analysis and report preparation $ 3,000

Study 103 Quantify nearshore zooplankton abundance and taxonomic composition
- Job 1: Sample zooplankton at selected nearshore sites $ 5.000
- Job 2: Identify and enumerate zooplankton $13.000
- Job 3: Data analysis and report preparation $ 4.000

Study 104 Estimate relative abundance and taxonomic composition of benthic invertebrates
- Job 1 Sample benthic invertebrates at selected nearshore locations $ 5.000
- Job 2 Count and identify benthic invertebrates $ 5.000
- Job 3 Data analysis and report preparation $ 3.000

Study 105 Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan
- Job 1 Develop predictive models of year class strength of nearshore fishes $4,000
- Job 2 Report preparation $ 3,000

Study 106 Effects of an artificial reef on smallmouth bass abundance
- Job 1 Relative abundance of smallmouth bass observed by SCUBA $ 5.000
- Job 2 Relative abundance of smallmouth bass collected by gill nets $ 5.000
- Job 3 Data analysis and report preparation $ 4,000

Total Estimated Cost $99,000